# Natural Factors Affecting Human History

Prepared by Robert G. Bedrosian



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**Ellsworth Huntington** (1876-1947)

Huntington, professor of geography at Yale University from 1907 to 1915, was a scholar, explorer, and author of numerous works on geography, climate, and civilization. His writings, most of which remain unsurpassed, are of critical importance for historians.

The Historic Fluctuations of the Caspian Sea, from *Bulletin of the American Geographical Society*, Vol. 39, No. 10 (1907), pp. 577-596.

The Pulse of Asia, *a journey in Central Asia illustrating the geographic basis of history* (New York, 1907), in 497 pdf pages.

**The Climate of Ancient Palestine**, in three parts, from *Bulletin of the American Geographical Society*, volume 40 (1908): 1; 2; 3.

Asia, a Geography Reader (New York, 1912), in 400 pdf pages. The *Geography Reader* series was intended for High School students, and today is perfect for college and graduate students. Written in beautiful clear English, this book covers the area from Arabia through Syria and Mesopotamia, Asia Minor, the Armenian Plateau, Caucasia, Persia, Central Asia, Korea, China, Japan, Indo-China, Malay Peninsula, and India.

> Another volume in this wonderful series also is available: Isaiah Bowman's South America, a Geography Reader (Chicago, 1915), in 410 pdf pages.

Civilization and Climate (New Haven, 1915), in 373 pdf pages.

Terrestrial Temperature and Solar Changes, from *Bulletin of the American Geographical Society*, Vol. 47, No. 3 (1915), pp. 184-189.

Climatic Variations and Economic Cycles, from *Geographical Review*, Vol. 1, No. 3 (Mar., 1916), pp. 192-202.

Climatic Change and Agricultural Exhaustion as Elements in the Fall of Rome, from *The Quarterly Journal of Economics*, Vol. 31, No. 2 (Feb., 1917), pp. 173-208.

The Sun and the Weather: New Light on Their Relation, from *Geographical Review*, Vol. 5, No. 6 (Jun., 1918), pp. 483-491.

World Power and Evolution (New Haven, 1919), in 294 pdf pages.

Principles of Human Geography, co-authored by Sumner Cushing (New York, 1922, second edition), in 458 pdf pages.

Sunspots and Weather, from *Geographical Journal*, Vol. 63, No. 6 (Jun., 1924), pp. 557-560.

The Valley of the Upper Euphrates River and Its People, from *Bulletin of the American Geographical Society*, Vol. 34, No. 4 (1902), pp. 301-310 and No. 5 (1902), pp. 384-393 in 22 pdf pages. This article contains fascinating observations on the lands and peoples of Harput, Malatya, Shiro, and Dersim, with rare photographs.

Through the Great Canyon of the Euphrates River, from *Geographical Journal* vol XX (London, 1902), pp. 175-200 with a map and nine illustrations, in 21 pdf pages. Huntington was accompanied by Armenian guides on boats made of inflated animal skins, the same type that Herodotus described Armenians using in Book I.194 of his *History* in the 5th century B.C. Huntington comments on Armenian villages and life in the first few years of the 20th century.

Other Writings by Huntington, at Internet Archive.

**Ellen Churchill Semple** (1863-1932)

Selected Writings of Ellen Churchill Semple, in 527 searchable pdf pages. The 18 articles in this download appeared in various journals during the years 1901-1931.

Contents:

*Mountain Passes: A Study in Anthropogeography*, from *Bulletin of the American Geographical Society*, Vol. 33, No. 2 (1901), pp. 124-137, and Vol. 33, No. 3 (1901), pp. 191-203, in 29 pdf pages.

*Geographical Boundaries*, I and II, from *Bulletin of the American Geographical Society*, Vol. 39, No. 7 (1907), pp. 385-397, and Vol. 39, No. 8 (1907), pp. 449-463, in 30 pdf pages.

*Oceans and Enclosed Seas: A Study in Anthropo-Geography*, from *Bulletin of the American Geographical Society*, Vol. 40, No. 4 (1908), pp. 193-209, in 18 pdf pages.

*Geographical Location as a Factor in History*, from *Bulletin of the American Geographical Society*, Vol. 40, No. 2 (1908), pp. 65-81, in 18 pdf pages.

*Coast Peoples*, in two parts from *Geographical Journal*, Vol. 31, No. 1 (Jan., 1908), pp. 72-90, and Vol. 31, No. 2 (Feb., 1908), pp. 170-187, in 39 pdf pages.

*The Operation of Geographic Factors in History*, from *Bulletin of the American Geographical Society*, Vol. 41, No. 7 (1909), pp. 422-439, in 19 pdf pages.

*The Barrier Boundary of the Mediterranean Basin and Its Northern Breaches as Factors in History*, from *Annals of the Association of American Geographers*, Vol. 5 (1915), pp. 27-59, in 38 pdf pages.

*Pirate Coasts of the Mediterranean Sea*, from *Geographical Review*, Vol. 2, No. 2 (Aug., 1916), pp. 134-151, in 19 pdf pages.

*Climatic and Geographic Influences on Ancient Mediterranean Forests and the Lumber Trade*, from *Annals of the Association of American Geographers*, Vol. 9 (1919), pp. 13-40, in 29 pdf pages.

*The Ancient Piedmont Route of Northern Mesopotamia*, from *Geographical Review*, Vol. 8, No. 3 (Sep., 1919), pp. 153-179, in 28 pdf pages.

*Geographic Factors in the Ancient Mediterranean Grain Trade*, from *Annals of the Association of American Geographers*, Vol. 11 (1921), pp. 47-74, in 29 pdf pages.

*Review: The Regional Geography of Turkey: A Review of Banse's Work*, from *Geographical Review*, Vol. 11, No. 3 (Jul., 1921), pp. 338-350, in 16 pdf pages.

*The Influence of Geographic Conditions upon Ancient Mediterranean Stock-Raising*, from *Annals of the Association of American Geographers*, Vol. 12 (1922), pp. 3-38, in 37 pdf pages.

*The Templed Promontories of the Ancient Mediterranean*, from *Geographical Review*, Vol. 17, No. 3 (Jul., 1927), pp. 353-386, in 36 pdf pages.

*Ancient Mediterranean Agriculture:* Part I, from *Agricultural History*, Vol. 2, No. 2 (Apr., 1928), pp. 61-98; and Part II: Manuring and Seed Selection, Vol. 2, No. 3 (Jul., 1928), pp. 129-156, in 68 pdf pages.

*Ancient Mediterranean Pleasure Gardens*, from *Geographical Review*, Vol. 19, No. 3 (Jul., 1929), pp. 420-443, in 25 pdf pages.

*Irrigation and Reclamation in the Ancient Mediterranean Region*, from *Annals of the Association of American Geographers*, Vol. 19, No. 3 (Sep., 1929), pp. 111-148, in 39 pdf pages.

*Domestic and Municipal Waterworks in Ancient Mediterranean Lands*, from *Geographical Review*, Vol. 21, No. 3 (Jul., 1931), pp. 466-474, in 10 pdf pages.

Influences of Geographic Environment, on the basis of Ratzel's system of Anthropo-Geography (New York, 1911), in 719 pdf pages.

**Alexander Chizhevsky** (1897-1964)

Physical Factors of the Historical Process, from the journal *Cycles* January (1971) pp. 11-27. Translated from Russian and condensed by Vladimir P. de Smitt, this is the text of an important paper delivered at the American Meteorological Society in 1926, in 17 pdf pages.

**Richard B. Stothers** (1939-2011)

Ancient Aurorae, from *Isis*, Vol. 70, No. 1 (Mar., 1979), pp. 85-95, in 12 pdf pages.

Solar Activity Cycle during Classical Antiquity, from *Astronomy and Astrophysics* 77(1979), pp. 121-127, in 7 pdf pages.

Historic Volcanism, European Dry Fogs, and Greenland Acid Precipitation, 1500 B.C. to A.D. 1500, from *Science*, vol. 222(1983) in 3 pdf pages.

Volcanic Eruptions in the Mediterranean before AD 630 from Written and Archaeological Sources, by Richard B. Stothers and Michael R. Rampino, from *Journal of Geophysical Research* 88 (1983), pp. 6357-6371, in 15 pdf pages.

Dark Lunar Eclipses in Classical Antiquity, from *British Astronomical Association* 1986 pp. 95-97, in 2 pdf pages.

Volcanic Winters, by Michael R. Rampino, Stephen Self, and Richard B. Stothers from *Annual Review Earth Planet* 1988(16), pp. 73-99, in 27 pdf pages.

Cloudy and Clear Stratospheres before A. D. 1000 Inferred from Written Sources, from *Journal of Geophysical Research*, vol. 107 (2002), in 10 pdf pages.

Ancient Scientific Basis of the "Great Serpent" from Historical Evidence, from *Isis*, Vol. 95, No. 2 (June 2004), pp. 220-238, in 20 pdf pages.

Unidentified Flying Objects in Classical Antiquity, from *Classical Journal*, vol. 103.1, 2007 pp. 79-92 with important bibliography, in 15 pdf pages.

Ancient Meteorological Optics, from *The Classical Journal*, Vol. 105, No. 1 (October 2009), pp. 27-42, in 16 pdf pages.

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Humanutics Series, at Internet Archive.

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The above letter has been submitted to Sir Alexander Kennedy, who asks us to say that he much regrets the misrepresentation of Professor Derry's opinions in the footnote, which was based entirely on Dr. Dalbey's letter.

ED. *G.J.*

### Sunspots and Weather.

On my return from a recent journey to Asia and Australia my attention was called to the *Geographical Journal* for last October containing a review of a book by Dr. Visher and myself on 'Climatic Changes.' At almost the same time a review of my 'Earth and Sun' has come to hand in the February number. It is always in order, I believe, to correct errors in such reviews, and I therefore ask you to print this letter.

The review of 'Climatic Changes' was written in a thoroughly fair-minded spirit, a spirit which I fully appreciate in view of the fact that some of the conclusions set forth in that book are novel and disconcerting even to the authors. Nevertheless the review may lead to a misunderstanding of the position of Dr. Visher and myself in certain respects. For example, it states that according to our solar hypothesis "when the continents were highly emergent, a rapid increase in sunspots resulted in a Great Ice Age. The terrestrial conditions change more slowly than the solar, hence the phenomena of interglacial periods." This seems to suggest that we advocate the hypothesis that a single period of activity of the sun was somehow able to produce both glacial and interglacial epochs. Our actual hypothesis is that during a single period of emergent continents there were a number of epochs of solar activity.

Again, the reviewer states that in 'Climatic Changes' "arguments are adduced which suggest that the sunspots, owing to their effect on storminess, may themselves play a part in the crustal changes, the rapid fluctuations of the barometric pressure acting like the blows of a hammer in fissuring the crust and causing earthquakes." This gives the idea of a degree of violence in atmospheric movements such as we certainly did not intend to convey. Our position is briefly stated as follows: "Apparently earthquakes and crustal movements are somehow related to sudden changes in the load imposed on the Earth's crust by meteorological condition" (p. 306). ". . . It must not be supposed, however, that meteorological conditions are the cause of earthquakes and of movements of the Earth's crust. There is . . . a great difference between the cause and the occasion of a phenomenon" (p. 307). ". . . The force that causes such movements would be the pull of gravity upon the crust surrounding the Earth's shrinking interior" (p. 310). But this hypothesis is "non-essential" and "still so new that only the first steps have been taken in testing it" (p. 314).

Another wrong impression may be gained from the reviewer's statement that "there is a solid impediment to believing that the solar variation is controlled by the 'nearest fixed stars.' How can they be responsible for the eleven-year cycle? And if they do not control the large variation we do see, why make them responsible for a larger variation we are asked to believe in without other reason than the convenience of the argument?" The answer is that nowhere in 'Climatic Changes' is there any hint that the stars cause the eleven-year cycle. Our hypothesis is expressed as follows: "Numerous good thinkers from Wolf (who first prepared the sun-spot numbers) to Schuster have held that the sunspots owe their periodicity to causes outside the sun. The only possible cause seems to be the planets, acting either through gravitation, through forces of an electrical nature, or through some other agency" (p. 61). And on a later page, "This seems to indicate that there is some

truth in the hypothesis that sunspots and other related disturbances of the solar atmosphere owe their periodicity to the varying effects of the planets as they approach and recede from the sun in their eccentric orbits, and as they combine or oppose their effects according to their relative positions. This does not mean that the energy of the solar disturbances is supposed to come from the planets, but merely that their variations act like the throwing of a switch to determine when and how violently the internal forces of the sun shall throw the solar atmosphere into commotion. This hypothesis is by no means new, for in one form or another it has been advocated by Wolfer, Birkeland, E. W. Brown, Schuster, Arctowski, and others" (p. 243).

Only when we had come to the conclusion that the periodicity of sunspots is apparently due to the action of the planets did it occur to us to inquire into any possible relation between climate and the fixed stars. Our reasoning was simply that if the planets affect the sun, the nearer stars, which are vastly larger and hotter than the planets and presumably have far more active atmospheres, may produce equal or greater effects in spite of their far greater distances. The probability of such an effect is increased if Schuster is right in his suggestion that the relation between the planets and the sun may be electrical rather than gravitational.

Turning now to 'Earth and Sun' we find that book reviewed in a spirit wholly different from that animating the review of 'Climatic Changes.' Aside from expressing an almost violent dislike not only for all the conclusions in the book but for all the facts, Mr. Brunt makes five specific criticisms, four of which are unwarranted, while one is warranted but insignificant.

1. The first criticism is this: "Such a well-known solar relation as the sunspot variation with the diurnal range of the horizontal component of the Earth's magnetic field finds no mention." If Mr. Brunt had examined the index, the heading "magnetism" or "terrestrial magnetism" would have led him to a reference to "horizontal intensity." At the top of page 101 he would have read, "The evidence of some kind of electrical or magnetic connection between the Earth and the sun seems conclusive. The best known evidence is perhaps the close correspondence between solar disturbances and perturbations of the magnetic needle." This correspondence is illustrated on page 102 by some curves prepared by Dr. Bauer of the Carnegie Institution of Washington. At the bottom of page 101 it is stated that he bases his magnetic curve on "the average horizontal intensity of terrestrial magnetism for each month modified by the average diurnal range of the same condition."

2. Mr. Brunt criticizes my statement that Humphreys' curves of temperature and sunspots "show clearly that the Earth's temperature rises when sunspots are few and *vice versâ*." He cites 1870 and 1912 as examples of disagreement. The implication is that I have overlooked such disagreements. On the contrary, in the second sentence after the one quoted by the reviewer I quote with approval a statement by Humphreys as to "marked discrepancies from time to time" between the two curves. The next paragraph discusses the cause of these discrepancies and ends with these words: "It appears that when the effect of the seasons and of short fluctuations is eliminated as in Fig. 1, at least four-fifths of the Earth's variations in temperature have been due to changes in the sun." The remaining fifth is ascribed to terrestrial causes among which volcanic dust appears to have been important, especially in 1912, as any careful reader can at once see from the text and diagram.

3. Mr. Brunt criticizes my use of correlation coefficients to determine the possibility of a relationship between a curve showing variations in planetary

movements and the curve of sunspots. "Had the author," he says, "chosen any other curve with a period round about eleven years, then so long as it coincided in phase with the sunspot period near the middle of the range, it would naturally give an appreciable coefficient of correlation with the sunspot curve."

This is perfectly true, but it is in no sense an argument against the possibility of a relationship between sunspots and the planets. The point is that although scores of able investigators have searched high and low they have not yet found *in nature* any curve of obviously non-solar origin that agrees with the sunspots in any such fashion as does the planetary curve. Anybody can make such a curve and fit it to the sunspot curve, but no one appears as yet to have found a natural curve of non-solar origin which agrees with the sunspots more closely than does the planetary curve. Having found that there is a remarkable similarity between the two curves the use of correlation coefficients is merely a convenient method of finding out how closely the curves agree and how likely we should be to find such an agreement among a series of curves selected at random.

4. Another of Mr. Brunt's specific criticisms is as follows: "The author quotes a considerable amount of observational data in some of his tables, but seldom gives references to the source from which they are taken." As a matter of fact, except in the case of the well-known facts as to the periods, sizes, and other conditions of the planets, the text and footnotes state where all the observational data were obtained. It would have been useless to repeat references to Wolf, Wolfer, the Monthly Weather Review, or the Greenwich tables each of the scores of times that sunspots are mentioned.

5. But Mr. Brunt is not always wrong. He is right in saying that in Table 19 a number of meteorological records have been ascribed to Kew instead of Greenwich.

In conclusion, is it not possible that a review which errs in its details in four cases out of five may require some modification in its main conclusions as to the worthlessness of 'Earth and Sun'?

ELLSWORTH HUNTINGTON.

Yale University, New Haven, Conn.,
26 March 1924.

Considerations of space make it impossible to deal fully with Prof. Huntington's replies to the reviews in this *Journal* of his two books. His explanation of points in the first will assist the student to form conclusions on these very debatable subjects. But we are bound to maintain our objection to the hypothesis of stellar influence on sunspots and on the Earth for the reasons concisely given in our review.

When the second book came for review, it seemed well to invite the opinion of a man eminently fitted by academic training and long practical experience of astro-physics and meteorology to form a sound judgment. The result was, as Prof. Huntington says not unfairly, "the expression of an almost violent dislike for all the conclusions. . . ." In this feeling Mr. Brunt is not alone, as may be seen by reference to other reviews of the book in scientific journals. Judgments of what constitutes a valid connection must be based to a large extent on feeling and instinct. Mr. Brunt has sent a reply to the above letter, which is summarized briefly thus: He still cannot find in the statement on page 101 or elsewhere a clear statement of the relationship between magnetism and sunspots; he considers the discordances in 1870 and 1912 fatal to any close connection between sunspots and Earth-temperatures,

especially since the temperatures discussed are for restricted regions of the globe. He maintains his judgment on the argument by correlation coefficients; but admits that the failure to find some important references to authorities blinded him to full references for other data. The question must be left to the judgment of individual readers, and unanimity in so speculative a question is not to be expected. But we should add that a recent publication of the Air Ministry (*Geophysical Memoirs*, No. 20) gives a very remarkable curve showing an undoubted relation between sunspots and the level of Victoria Nyanza, which would have been most useful to Prof. Huntington's argument.

ED. *G.J.*

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# MEETINGS: ROYAL GEOGRAPHICAL SOCIETY: SESSION 1923–1924

**Twelfth Evening Meeting, 5 May 1924.**—The President in the Chair.

ELECTIONS.—The Dowager Lady Buxton; The Lord Biddulph; Bayard Colgate; Thomas Dinesen, V.C.; Thomas Stanley Glover, B.A., SC.; Percy William Haller; The Rev. Robert Hughes, PH.D., D.C.L., B.D.; Prof. Ellsworth Huntington; George Duncan Jack; Dr. N. L. Linebaugh, D.D., LL.D.; C. Gilbert More; Lady Dorothy Hope Morley; Herbert Court Osborne; Captain H. G. Reed; Bernard Joseph Reilly; Edward George Turner; Dr. D. N. Wadia; Edwin Archer Waymark, A.C.I.I.

PAPER: From East to West across Northern Australia. Michael Terry.

**Thirteenth Evening Meeting, 19 May 1924.**—The President in the Chair.

ELECTIONS.—Frederick Alfred; Major Albert Edward Bennetto, F.Z.S.; Ernest Brocklebank, J.P., F.R.S.A.; Captain Percy Chambers Cabot; Percy Campbell; Hon. Margaret Bruce Chaloner; Captain David H. Cole, M.B.E.; Sergeant Albert Coleman, A.E.C.; William Courtenay; Mrs. Gertrude Hill Cuthbert; Captain N. Douglas-Stephenson, M.C.; Lady Florence M. Downes; Rev. Harold Garner; J. F. Gibbons, M.A.; William Edward Hope, F.R.C.I.; Godfrey Cresswell Hutchinson; Wilfred Irwin; William John Keeling, M.C.; William Henry King; Miss Marie Mackinnon; Gordon Law Morris; Lieut.-Colonel A. Hume Nicholl, C.B.E., F.Z.S.; Miss Gladys Mary Oram; Miss Daisy Pyser; William G. Riley; Major Raymond Henry Raymond Smythies; Miss Violetta Thurstan; Major Chaplin Court Treatt; Mrs. Marion Watson; Lieut.-Colonel Sir Archibald Weigall, K.C.M.G.

PAPER: Through Kufra to Darfur. Ahmed Hassanein Bey.

**Seventh Afternoon Meeting, 12 May 1924.**—The President in the Chair.

PAPER: The proposed adoption of a Standard Figure of the Earth. Discussion opened by Captain G. T. McCaw.

# Physical Factors of the Historical Process

by A. L. TCHIJEVSKY*

*Editor's Note:* Even though research on the correlation between physical reactions of organisms to environmental fluctuations has progressed to investigations of less obvious phenomena than sunspots, this paper remains a landmark in the literature. The data and the tools have both been developed far beyond the state that obtained when Professor Tchijevsky wrote this paper, but as yet no conclusive case—pro or con—has been developed. Extensive work has been done on sunspots as well as on human excitability, but the task of establishing any relationship of the two remains one of the more important unfinished projects.

Our previous publication of this paper is out of print; it is reprinted here in response to numerous requests. *G.S.*

## FOREWORD

At a time when serious attention is being concentrated on the study of economic and political laws, the study of the influence of natural factors on the mass of behavior of humanity has perhaps been rather neglected.

The object of this paper is to present a condensed abstract of the work of the Russian Professor, A. L. Tchijevsky, dealing with the influence of Sunspot Activity upon the whole historical process.

Holding no personal brief for the theories of Professor Tchijevsky, I tried only to be as exact as possible in my translation of his work. *Vladimir P. de Smitt*

## INTRODUCTION

In reviewing human history, it is found that even the most prominent intellects have been powerless, except in rare instances, to foretell even the immediate future of their nations or countries or the outcome of wars and revolutions.

Historical events have always indicated different results than those which were anticipated at their beginning.

Humanity has never formulated any law which would govern any particular historical facts or sequence of facts throughout the many centuries of its culture, despite the gradual and progressive development of precise sciences. The bases for the destinies of History seem chaotic and the allotment of events in space and time seems unruled by any law.

Under this conception were equally regarded short periods of History with separate events (wars, revolutions, etc.) and whole epochs of hundreds and thousands of years covering whole cultures and civilizations of humanity.

The comparative method adopted quite recently in the study of History consists essentially in detecting the general course of development of different historical events and in discovering the exact laws pertaining to the event.

Students of History proved that individual cases of more or less similar character, and long historical epochs have many similar traces in their progressive development; in other words, the events of History repeat themselves and this makes possible the deduction of certain generalizations (K. Lamprecht, O. Spengler). J. de Condorcet (1743–1794) in his famous work "Esquisse d'un Tableau Historique des Progress de l'esprit humain" emphasized the establishing of a hypothetical history of the people by depicting facts from the histories of all nations and their mutual relations.

History was justly known up to the present as Knowledge, not as Science. This opinion was given by Arthur Schopenhauer (1788–1860) in his "Die Welt als Wille und Vorstellung." De Fontainaille in XVIII Century called History a "convenient tale" (L'histoire n'est qu'une fable convenue).

Undisputably, the first and principal property of Science is the presence of definite Laws governing the facts in all their integral parts.

*Professor Tchijevsky was Assistant, Astronomical Observatory; Collaborator, Institute of Biological Physics, and Fellow, Archeological Institute; Moscow.
This paper was translated and condensed by Vladimir P. de Smitt when he was Research Associate, Geology, Columbia University and Senior Research Analyst, Library of Congress. The paper was presented at the annual meeting of the American Meteorological Society in December 1926.

Inefficiency in finding out the laws of History makes some people assume the hand of Providence guiding the destinies of men, others see that chance and accidental facts with no general law are essential in History and yet others regard the human will as the principal factor changing the flow of historical events, whereas the acts of this will never could be accounted for nor classified.

Many branches of human knowledge in the XIX and XX Centuries made such progress that they became indispensable and obviously necessary in the practical every-day life of men. But what do we owe to History?

A man who would speak of the "practical purposes in History" would be called irrational.

Notwithstanding the enormous amount of historical material collected, the best and finest methods adopted for studying it, the colossal work done by scientist-historians: History at its present level gives to humanity nothing of social-practical value.

History presents knowledge of material already dead and useless for the ever progressive life. It presents archives where researches are seldom made, to answer the questions of the present day; the "lessons of History" have taught nothing to anyone, and even those with intimate knowledge of History made the same mistakes that had already been made years before.

Thus, not until the time when man ceases to repose only in providential guidance in the progress of History, and no longer regards the constantly changing unstable human will as a predominant factor, will he be able to advance in search of laws which govern his daily activity as well as his centuries old destinies.

The fact must be noted that the sphere of exact disciplines of Science never touched History in its entirety, even when they were brought into the domain of psychology, and physico-mathematical laws were admitted to govern the processes of sensation.

The English historian, H. T. Buckle (1821–1862), equipped with the richest data accumulated by science in the domains of History, Geography, Economics and Statistics, made an endeavor in his work "History of Civilization in England," to show that the principles and methods of natural sciences must be applied to History, because History is a reciprocal reaction between man and nature.

Nearly at the same time, the American chemist and historian, J. M. Draper (1811–1882) in his outstanding "History of The Intellectual Development of Europe" (1856), proposed the idea that the historical evolution of peoples is being governed by natural laws and is under the influence of the physical agents of nature.

But these endeavors were fruitless because of the existing general opinion of the independence of the psychical and social activities of man from any physico-chemical factors in the world of surrounding nature.

Contemporary sciences try to bring all psychological phenomena to physiological processes in which they seek and find a physico-chemical basis: the mechanics of the elementary particles in the nerve centers.

The success of biophysics during recent years begins to deprive man and his higher nervous activity of the mysterious halo which surrounded them during so many thousands of years.

The physico-mathematical analysis when applied to the investigation of psychical processes, shows that their functions can be expressed in physico-chemical reactions and explained by mathematical formulae.

Considering the psychical activity of man to be in the domain of ordinary natural phenomena, contemporary science similarly supposes a certain dependence to exist between the manifestation of man's intellectual and social activities and a series of powerful phenomena of surrounding nature. The earth, taken as a whole with its atmo, hydro and lytho spheres and also with all the plants, animals and the whole human kind,—the biosphere—must be considered by us as one common organism.

From this viewpoint, it must be admitted, *a priori*, that the greatest events in human societies enveloping entire races through participation of great masses of population must occur simultaneously with some variations or alterations in the forces (factors) of surrounding nature.

Professor Tchijevsky undertook a research of the successions of historical events with relation to the periodical activity of the sun. The results of this research are presented by him in his "Investigation of The Relationship Between The Sunspot Activity and The Course of The Universal Historical Process from the V Century B.C. to the Present Day."

By the "universal historical process," Professor Tchijevsky means the simultaneous course of social evolution in all groups of human society, dependent or independent of each other according to their geographical location. In using this term, he touches to some extent upon the age-old tendency to view History as one unified whole. Thus, in the Second Century B.C., the Greek historian Polibios and eighteen centuries later Bishop J. Bossuet (1627–1704) emphasized the necessity of acquiring a uniform and universal standpoint for historical study.

Bossuet in his "Discours sur l'Histoire Universelle" (1681) says that in full analogy to one common geographical chart which generalizes all countries and all nations, a uniform point of view upon History would help fusion of the histories of various national developments into one unique process—a universal history of humanity.

## I ACTIVITY AND GENERAL INFLUENCE OF THE SUN

The sun is an enormous generator of electric energy and emits it in the form of radiation and induction. The sun is surrounded by an electro-magnetic field, the limits of which reach beyond the farthermost planet Neptune, and therefore the earth with its electro-magnetic field is in the sun's field of tremendous power.

The inner life of the sun undergoes rhythmical periodical fluctuations which are manifested on its outer surface by the appearance and disappearance of sunspots, by their number and by other facts.

This characteristic of the sun undergoes regular periods of minimum, increasing, maximum and of decreasing activity.

The entire cycle of the sunspot activity comprises from seven to sixteen years (more often from nine to thirteen years). This periodicity was first discovered by H. von Schwabe (1851). The average length of this period was established later and equals eleven years, thus repeating itself nine times in a century.

Greater and smaller periods have been also found and calculated by several scientists: De Mairan (1746), A. P. Gansky, A. Schuster (1906), Dr. Elsa Frenkel (1913), H. Turner (1913), Bruckner and others.

The complication of the question and the diversity of opinions obliged the author to make inquiries at the best observatories concerning the latest works in this field (Mount Wilson Solar Observatory in Pasadena–Dr. Seth B. Nicholson, Eidgenossische Sternwarte in Zurich–Professor A. Wolfer, Royal Observatory at Greenwich–Professor F. W. Dyson, Steward Observatory in Arizona–Dr. A. E. Douglass, and others.)

By classifying the answers, the one undoubtedly established period is the eleven year period but certainly there exist other periods which have not yet been sufficiently studied owing to lack of material.

The activity of the sun expresses itself in spots, prominences, filaments, foculae, corona, etc., but a special interest must be attached to sunspots which are directly connected with the construction of the sun itself.

As is well-known, the spots appear in two belts on the surface of the sun and cross the sun's disc in thirteen-fourteen days corresponding to the period of rotation of the sun. Some spots reappear a second time within thirteen-fourteen days after their disappearance.

Many observations of sunspots have been made by many scientists (Galilei, Herschel, Zoller, Faye, Secchi, Moreux) and several hypotheses were worked out; nevertheless, the mystery of the spots is not yet solved.

The conspicuous work in this field must be credited to the American scientist, George Ellery Hale* and the French scientist, H. Deslandres. Hale made the assumption that sunspots are huge electrical whirls. Rowland, Young, Zeeman, showed the slitting of bifurcation of spectral lines in a magnetic field which in the case of the sun proves the existence of a magnetic field in the sunspots.

Therefore, it can be assumed that the spot is an enormous magnet with one pole turned toward the earth and the other lying deep in the sun's interior.** Evershed and St. John noticed movements in the spots ("solar vortices" according to Hale).

During the period of the maximum of the sun's activity, all the sun's phenomena acquire tremendous dimensions. The sun ejects streams of anode and cathode rays which ionize the earth's atmosphere (Birkeland, Arrhenius, Nordmann, Paulsen, Villards) and create certain physical effects.

It is to be noted that the greatest perturbations of the earth's magnetism always coincide with the time of passage of large spots through the central meridian of the sun (Loomis, Lord Kelvin, Terby), and according to Ricco, lagging for about two days after this passage.

Some physical effects of sunspot activity, on the earth, which are definitely proved, or under probation at present, are the following:

Magnetic Storms (Sabine, Wolf, Gautier-1852)
Aurora Borealis (Fritz-1853, Loomis)
Cirrus, Cirro-stratus, Cirro-cumulus clouds (Klein, Paulsen)
Halos in the Atmosphere
Fluctuations of the Atmospheric Electricity (Chree, Bauer)
Thunderstorms (Hess, Herbiger, Sviatsky)
Tropical and Extra-tropical Cyclones, etc. (Meldrum)
The Color of the Sky (Busch)
The Temperatures of the Air at the Earth's Surface (Koppen, Nordmann, Mielke-1913).
Surface Tempratures of Some Oceans (Atlantic off Norway)
Polar Icebergs
Precipitation (Symons, Moreux, and others)
Atmospheric Pressure (Walker, Leist, Fedoroff)
Fluctuations of Climate (Bogolepoff)
Earthquakes

The parallelism of three curves, that of the sunspot activity, of the activity auroras and of the fluctuation of the earth's magnetism, must be noted.

*Probably the latest works of Professor Huntington were unknown to Professor Tchijevsky due to the political conditions. (V. de S.)
**It is now known that sunspots usually occur in pairs of opposite polarity. It is as if they were the ends of horeshoe mag. netc buried in the sun. Ed.

The general influence of the sun on the development of organic life has been observed with greatest interest since ancient times by many philosophers and thinkers. In his present study, the author will begin with the sun's general influence and then gradually proceed to the specific influence.

Men have always felt their dependence of the sun and consequently it is not surprising that the sun has been worshipped as the chief god: Hindoo - Suria and Savitar; Persian - Ormusd; Assyrian - Isdubar and Nimrod; Babylonian - Marduk; Egyptian - Osiris, Ptha, Ra; Ancient Greeks - Apollo, Helios, Febos; etc.

Thus, the doctrine of the activities of the ever-vivifying central fire which has been regarded as the origin of all living, occupies the first place in all mythologies, philosophies and arts.

Even in remotest ancient times, thinkers tried to find correlation between the condition of human organism and the fluctuations of surrounding physical nature which in a certain way depend upon the sun. (Herodotes, Hypocrates, Aristotle, Strabon, Plinius).

From the point of view of contemporary science, all the various and different phenomena: the chemical transformations in the earth's crust, the dynamics of the planet itself and its atmo, hydro and lytho spheres take place under the direct action of the sun. On the equator, all chemical processes are of the maximum activity.

Therefore, there exist certain chemical zones on our planet (Fersman) and corresponding special zones in the soil (Dokoutchaeff).

The direct influence of the sun's energy on the green of plants is well known; it helps the transformation by the plants of inorganic matter into organic. The red rays of the sun's spectrum dissociate carbon dioxide and synthesize carbo-hydrates (K. Timiriazeff 1920).

The influence of the sun upon live organisms cannot be formulated by contemporary science in one universal formula, and therefore the effects of sunlight upon the different components of a living organism must be enumerated.

For example, ultra violet rays affect the oxidating processes in the cellular tissues (Quincke) and increase the exchange of gasses in the living muscular and nervous tissues (Moleschott, Fubini).

This influence of the sun on human organism results in chemical changes in the pigment of the skin, in the changing of the heart-beat, in the alterations in the chemical composition of the blood and the latter results in changes in the general condition of the organism and its nervous tonicity (Lenkei, Behring, Hasselback, Nogier, Aimes, Rollier, Revillet, Marques, d'Oelsnitz, Robin, Moleschott, Loeb, I. Newton, Professor Bechtereff, Lombroso).

The influence of the sun on the climate explains the existence of zones of highest and lowest races and cultures. Therefore, the forces of external nature liberate or bind man's spiritual energy which is in a potential state and thus make the intellect function or become stagnate.

If the different amount of the sun's energy received by different climatic zones has such a great influence on humanity, the question arises: do the periodical changes of the sun's activity resulting in the amount of the emitted innumerable streams of electrical particles and electro-magnetic waves also have an influence upon humanity?

## II SYNCHRONOUS CORRELATION OF THE SUN'S PERIODICAL ACTIVITY AND THE PERIODICAL CHANGES IN THE UNIVERSAL HISTORICAL PROCESS

Researches were made in the works of:

Christian Horrebow (1718–1776) Danish Astronomer; Sir William Herschal (1738–1822) English Astronomer; W. S. Jevons (1835–1882) English Economist (his "Commercial Crises and Sunspots"); Koppen; N. C. Flammarion and Thoman Moreaux - French Astronomers; Professor A. E. Douglass of Stewart Observatory ("Climatic Cycles and Tree Growth"); D. O. Sviatsky and Professor V. M. Bechtereff - Russian Scientists; Rudolf Wolf - German Scientist ("Sonnenfleckenliterature" - 1856); and many others.

Since the year 1610, sunspots have been observed by means of telescopes. For the epochs prior to 1610, these spots were mentioned in Chinese annals, in some ancient Arabian, Russian, Armenian documents, in the public chronicles of some European cities (Chroniken der deutschen Stadte); and these sources helped the author to approximately define the periods of maximum activity of the sun beginning with the first-mentioned Chinese observations in the year 188 A.D., but of course these earlier observations lack any system and show great intervals, some of several decades.

A table of forty-five Chinese observations taken from the aforementioned annals for the period of 301–1205, was computed and published by the Japanese Astronomer, Shin Hiragama (Observatory 1889).

From the initial steps in these researches, the author was impressed by a most surprising fact: the fluctuations of the historical process are synchronous with the fluctuations in the physico-chemical processes in the sun's substance. Further investigation showed that notwithstanding the fact

that the mass human life never ceases even for a second in this or any part of the globe, its fullest development nearly covering the entire surface of the globe is attained at the times of maxima of sunspot activity.

The most difficult thing for the author was to adopt a uniform unit for measuring the statistics of the activities of human masses. Here were to be considered two factors: quality of the event (its importance) and quantity (number) of human masses participating.

Other factors such as the length of the event, the area occupied by it, etc., handicapped the formulation of the unit.

It was necessary to find out a generalizing method; i.e., such a method as would be applicable for recording any historical event. For this purpose, Professor Tchijevsky adopted the following moments of every mass event which had a more or less important historical value.

(1) The beginning of the event; i.e., the first rising of masses, and

(2) The moment of the highest tension (if such a moment can be strictly defined).

Greatest attention was paid to the dates of the starting of historical events; i.e., the dates of the first rising of human masses for attaining a certain cause.

The final deductions were arrived at after a long study of detailed statistical researches in the histories of 72 countries and nations of the world; these histories having been known to science from 500 B.C. to 1914, in other words, for 2414 years. The countries and nations involved in this study, were

IN EUROPE

| | | | |
|---|---|---|---|
| Greece | Switzerland | Spain | Denmark |
| Rome | Hungary | Ireland | Poland |
| Italy | Austro-Hungary | Scotland | Bulgaria |
| Germany | Turkey | Holland | Serbia |
| Gaul | Rumania | Netherland | Czechia |
| France | Russia | Norway | etc. |
| Iberia | Lithuania | Sweden | |

IN ASIA

| | | |
|---|---|---|
| China | Central Asia | Ceylon |
| Tibet | Hunns | East-Roman Empire |
| Mongolia | India | Turkey |
| Japan | Indo-China | Persia |
| Korea | Asiatic Russia | Palestine-Israel |
| Indonesia | Afghanistan | And other ancient people |
| Siberia | Arabia | |

IN AFRICA

| | | |
|---|---|---|
| Egypt | Congo | Morocco |
| Carthage | Sudan | Other African people |
| Mauritania | Abyssinia | European Colonies, etc. |

IN AMERICA

| | |
|---|---|
| Canada | Texas |
| United States | Mexico |
| California | Peru |
| Brazil | European Colonies etc. |

IN AUSTRALIA

| | | |
|---|---|---|
| European Colonies | Oceania | Tasmania |

For the purpose of studying the histories of these peoples, countries and states, all works and text books, (available under present conditions) in modern and ancient languages were consulted. This research permitted the author to state the following principal facts which characterize the course of the universal historical process, and which are based on numerical statistics.

1. As soon as the sunspot activity approaches its maximum, the number of important mass historical events, taken as a whole, increases, approaching its maximum during the sunspot maximum and decreasing to its minimum during the periods of the sunspot minimum.

2. In each century the rise of the synchronic universal military and political activity on the whole of the earth's territory is observed exactly nine times. This circumstance enables us to reckon that a cycle of universal human activity embraces eleven years (on the average).

3. Each cycle according to its historical psychological signs is divided into four parts (periods):

| | | |
|---|---|---|
| I. | Minimum of excitability . . . | 3 years |
| II. | Growth of excitability . . . | 2 years |
| III. | Maximum of excitability . . . | 3 years |
| IV. | Decline of excitability . . . | 3 years |

The number of historical events in each cycle are distributed approximately according to the data for 500 years (XV–XX Centuries) in the following manner (on the average):

| | | | |
|---|---|---|---|
| I period . . . | 5% | III period . . . | 60% |
| II period . . . | 20% | IV period . . . | 15% |

4. The course and development of each lengthy historical event is subject to fluctuations (periods of activity and inactivity) in direct dependence upon the periodical fluctuations occurring in the sun's activity. Formula: the state of predisposition of collective bodies towards action is a function of the sunspot periodical activity.

5. Episodical leaps or rises in the sun's activity, given the existence in human societies of polito-economical and

other exciting factors, are capable of calling forth a synchronic rising in human collective bodies. Formula: the rising of the sunspot activity transforms the people's potential energy into kinetic energy. Professor Tchijevsky's studies in the sphere of synthesizing historical material have enabled him to determine the following morphological law of the historical process.

6. The course of the universal historical process is composed of an uninterrupted sequence of cycles, occupying a period equaling in the average, eleven years and synchronizing in the degree of its military-political activity with the sunspot activity. Each cycle possesses the following historiopsychological characteristics:

(a) In the middle points of the cycle, the mass activity of all humanity, assuming the presence in human societies of economical, political or military exciting factors, reaches the maximum tension, manifesting itself in psychomotoric pandemics; revolutions, insurrections, expeditions, migrations, etc. - thus creating new formations in the existing separate states and new historical epochs in the life of humanity. It is accompanied by an integration of the masses, full expression of their activity and a majority government.

(b) In the extreme points of the cycle's course, the tension of the all human military-political activity falls to the minimum, giving way to creative activity, and is accompanied by a general decrease of military or political enthusiasm, by peace and peaceful creative work in the sphere of state organizations, international relations, science and art, with a pronounced tendency toward absolutism in the governing powers and a disintegration of the masses.

7. The maximum of human activities in correlation with the maximum of sunspot activity, expresses itself in the following:

(a) The dissemination of different doctrines (political, religious, etc.), the spreading of heresies, religious riots, pilgrimages, etc.

(b) The appearance of social, military and religious leaders, reformers, etc.

(c) The formation of political, military, religious and commercial corporations, associations, unions, leagues, sects, companies, etc.

8. It is impossible to overlook the fact that pathological epidemics also coincide very frequently with the sunspot maximum periods.

9. Thus the existence of a dependence of the behavior of humanity on sunspot activity should be considered established.

One cycle of the all-human activity is taken by the author for the first measuring unit of the historical process. The science concerned with investigating the historical phenomena from the above point of view, Professor Tchijevsky has named "Historiometry," in other words, the measuring of historical times (epochs) by means of physical units. The cycle taken as a unit called by him, "historiometric cycle."

Professor Tchijevsky summarizes his statistical researches in a table which he calls, "Historiometrical table for the period from the Fifth Century B.C. to the Twentieth Century A.D.

The author also gives two diagrams illustrating this table.

He determined from the trend of the universal history nine historiometric cycles in every century, which are numbered in the Table from 1 to 9. This is the first experiment in compilation of such a table and of course the table is open to considerable correction in the future.

This Table gives only the size of the concentrations of the newly arising historical events and the sizes of comparative lulls between these events. He gives the following explanation of the Table:

Beginning with the V Century B.C. to the A.D. XVI, the centuries are divided into nine equal periods of eleven years each. The years of the beginnings of every period are shown in brackets.

From the II Century A.D. to the XVI Century, inclusive, the sunspot activity is taken from historical sources; heavy figures show the probable dates of sunspot maxima; heavy dots show the more reliable ones.

From the XVII Century to the XX, the dates of maxima and minima sunspots are taken from astronomical telescopic observations (Meteorologischen Zeitschrift, Heft 10, s. 327–1922).

The diagrams show average curves of the fluctuations of the universal historical process of the entire earth during the period from V B.C. to A.D. XX.

The second diagram shows on a larger scale the parallelism of the curves of sunspot activity (lower curve) and of the universal human military-political activity (upper curve) from 1749 to 1922.

The abscissae of both diagrams correspond to years, and the ordinates to the number of important historical events and sunspots. Heavy dots mark the dates of sunspot maxi-and recorded from the first pretelescopic observations and, later, from 1810, were taken from the results of telescopic astronomical observations. Hyphens mark the minima.

The curves on both diagrams are only the average and give a general conception, to be amended in the future to eliminate possible errors.

The fact that both curves on the second diagram are strictly parallel after the telescopic observations have been introduced and thus reliable astronomical data obtained for sunspot activity, only emphasizes the correctness of the whole theory.

## III SOCIAL-PSYCHOLOGICAL CHARACTERISTIC OF A FULL CYCLE

The division of every cycle into four periods was the result of the study of the sequence of historical events in comparison with the trend of sunspot activity.

Entirely different events of universal history were analyzed, beginning with ancient Greek and Roman riots, insurrections and expeditions, and ending with revolutions and wars of recent years.

The formal resemblance in the development of different historical events, sometimes having nothing in common with each other neither in space nor in historical time but distinctly similar in their development, is the motive cause for assuming the existence of a definite periodical factor which stands outside of the influence of local, transitory and geographical conditions and which endows the course of quite different and various historical events with the same obligatory and almost universal inner law of sequence and morphologic identity. The outstanding feature of this law is that it is not absolutely stable, it varies only to a certain degree.

After synthesizing all the collected material, Professor Tchijevsky obtained for every period of his historiometric cycle the following characteristics, which are the generalized ideal conditions separated from various casualties or local and temporary influences.

### THE FIRST PERIOD
(Period of the minimum of excitability)

The characteristics of this period are:

Lack of unity in human masses.
Indifference of the masses to political and military questions.
Peacefulness of the masses.
Tolerance and forebearance of the masses.

The results of these characteristics are:

Lack of any desire to struggle for the right or idea, easy capitulation, desertion, etc.

Historical facts illustrating this period, are peace treaties, capitulations, occupations, decrease or parlimentarianism, strength of autocracies, and the ruling of minorities.

### THE SECOND PERIOD
(Growth of excitability)

This period is very complicated psychologically and historically and thus the researches made by the author were very extensive and the material collected very abundant. Therefore, only schematical extracts will be mentioned.

The characteristics of this period are:

Beginning of uniting of masses; new leaders appear, political, military, orators; new programs are worked out; increasing work and influence of the press; political and military questions arise and begin to predominate the masses.

The end of this period can prove stormy, producing impatient and nervous masses. The length of this period varies greatly, depending upon the length and range of sunspot activity and the numerous local factors and conditions which give different forms to the development of the whole period.

One of the most important properties of the military-political life of human societies in this period is the tendency of different nations to unite for common defense or aggression and the fusion of different political groups to oppose other groups.

Three principal phases of this period are: (1) The originating of new ideas in the masses; (2) the grouping of these ideas; (3) The crystallization of one predominent idea with concentration of numerous separate groups around one psychic center and on one unique idea.

These three phases of the second period sometimes develop themselves entirely mechanically with no individual participation of separate personalities and this prepares unexpected effects of unity in the masses in the forthcoming third period, the period of maximum excitability.

Thus arises the necessity of an urgent solution of a sole predominant question which holds the masses and which agitates them.

### THE THIRD PERIOD
(Period of maximum excitability)

This is the principal period of every cycle, which gives solution to the greatest problems of humanity. This period inspires nations to the greatest insanities, as well as to the greatest achievements.

The most prominent events of the universal human history occur in this period: such as, the greatest revolutions and wars which bring new eras into man's history, thus confirming the formula of Heraclites, "Polemos panton esti pater kai basileus" - "The war is the father and king of all."

Professor Tchijevsky, in his original work which is called, "The Foundation of Historiometry," gives a detailed analysis of the abundant material pertaining to this period, which he has collected; while in his present work, he only enumerates the principal factors, as follows: (1) The provoking

influence of leaders upon the masses; (2) The exciting effect of emphasized ideas upon the masses; (3) The velocity of incitability due to the presence of a single psychic center; (4) The extension area covered by the mass movements; (5) Integration and individualization of masses.

Unlike the pervious periods when nothing could excite the masses, the influence of a Leader has such a gripping effect during the third period that a single word or gesture from him at the important moment can raise the enthusiasm of the masses and move armies into action.

Professor Tchijevsky demonstrates that at the heat of these mass movements in history, stand the greatest military and political geniuses and spiritual leaders, and founders of nations and countries.

This period can be justly called the period of advent of the people and the expression of their voices.

Historians sometimes are at a loss to explain why ideas which may be freely and unhestiatingly discussed at this period, were considered unmentionable only one to three years previously.

The masses become more impatient, nervous and exacting. Riots, bloody conflicts, insurrections among the masses, are followed by the overthrow of all obstacles; the opposing elements are mercilessly destroyed, offering only feeble resistance as if being in a state of coma.

The masses are on their way to anarchy. In one word, the state of humanity is such as to demand an eruption. This state can be explained by an acute change in the nervous and psychic tonus of the masses. In these great tensions of humanity the sense of fear and self-defense may temporarily be atrophied or suppressed in individuals and in masses.

Thus the foundation is being prepared for the solutions of the greatest problems and questions of universal historical character; the foundation from which arises systems of human societies. Here take place events of a scale scarcely possible in other periods of the historiometric cycle.

Professor Tchijevsky states the fact that the greatest revolutions, wars and other mass movements which have created nations and whole systems of states; have given origin to the turning points of history; and have shaken the life of humanity on entire continents, tend to coincide with the periods of the maxima of the sun's activity, and to attain their maxima in the moments of the highest points of this activity.

The study of historical events in the third period allows the author to state the following facts pertaining to this period: The uniting of masses; appearance of leaders, military, political and social; triumph of ideas upheld by the masses; the maximum of parlimentary practices; democratic and social reforms; limiting of autocracies; insurrections, rebellions, mutinies, revolutions, wars, campaigns, expeditions, emigrations, migrations, persecutions, etc. For illustration, a few of the numerous facts which have been studied by Professor Tchijevsky are cited below:

(1) Turning points of the universal History

1491 - The fall of the Mahometan yoke in Spain.
Discovery of America
Beginning of modern history.
1789 - French Revolution
1917 - Russian Revolution

(2) Insurrections and Revolutions

1306 - Insurrection in England
1358 - Insurrection in France
1368 - Insurrection in China
1381 - Insurrection in England
1525 - Insurrection in Germany
1648 - Revolution in England
1789 - Revolution in France
1830 - Revolution of July
1848 - Revolution of February and All-European Crisis
1870 - Commune of Paris
1905 - Revolution in Russia
1917 - Revolution in Russia

(3) Crusades

| | | | |
|---|---|---|---|
| 1094-1096 | -First | 1203-1204 | -Fourth |
| 1147- | Second | 1224- | Fifth |
| 1187- | Third | 1270- | Seventh |

(4) Migrations of Nations

374, 409, 449 - 451 - 452, 568

(5) Persecutions of Christians

303, 362, 575, etc.

(6) Sanguinary events of universal history

1204 - Downfall of Byzantium
1572 - The Night of St. Bartholomew in France
1588 - Executions in London
1792 - Terror in France, etc.

(7) The rising of national leaders

395 - Allarick
441 - Attila
622 - Mohamet
1096 - Peter of Amiens
1402 & 1412 - John Guss
1429 - Joan of Arc
1489 - Savonarolla
1519 - 1525 - Luther, Zvingly
1537 - Ig. Loyola
1625 - Richelieu
1648 - Oliver Cromwell
1777 - Lafayette
1777 - Washington
1805 - Wellington
1848 & 1860 - Garibaldi, Bismarck
1870 - Moltke
1870 - Gambetta, Thiers
1917 - Lenin
Etc.

(8) Periods between the Greatest Battles During the During the Five Centuries B.C.

V Century - 490-480, 466-433, 433-425, 425-415, 415-405
IV Century - 390-371, 371-362, 362-340, 340-331, 331-301
III Century - 280-272, 272-260, 260, 241, 241-222, 222-212, 212-202
II Century - 197-190, 190-168, 168-102
I Century - 86-74, 74-66, 66-46, 46-30

(9) The duration of lengthy events is generally the multiple of ten or eleven years

| | |
|---|---|
| 375- 476 | (101 years) - Great migrations of peoples. |
| 622- 632 | ( 10 years) - Activity of Mohamet |
| 1389-1448 | ( 59 years) - Wars: Christians & Turks |
| 1460-1741 | ( 11 years) - War between White and Red Rose |
| 1489-1498 | ( 9 years) - Activity of Savonarolla |
| 1789-1804 | The beginning and final points of the great French Revolution. |
| 1848-1860 | Insurrection of Garibaldi |

And many other examples.

(10) Epidemic diseases

1370 - Cholera in Persia. (Hiragama mentions Chinese historians who tell of large sunspots at this time, which were seen with the naked eye.)
In the XIX Century -

| Sunspots | | Cholera Epidemics | | |
|---|---|---|---|---|
| Maxima | Minima | Beginning | Maxima | Ending |
| 1816 | 1823 | 1816 | 1817 | 1823 |
| 1829/37 | 1833 | 1827 | 1829-31 - 1837 | 1833 |
| 1848 | 1856 | 1844 | 1848 | 1847 |
| 1860 | 1867 | 1863 | 1863-66 | 1875 |
| 1870 | 1878 | | 1870-72 | |
| 1883 | 1889 | 1883 | 1883-86 | 1889 |
| 1894 | 1900 | 1890 | 1892-894 | |

### THE FOURTH PERIOD
(Period of decreasing excitability)

From the historical-psychological point of view, this period is of no less interest than the preceding one; it can also contain many important events which having been originated in general in the previous period, now complete themselves. Mass movements show their last convulsions as if before death. The masses become more and more inert and apathetic with a clearly proven tendency for peace. Lack of unity in the masses gives rise to disputes in collectives, unions and nations.

The physical exhaustion and fatigue of the masses produces a new psycho-physical state which may be called enervation.

These general properties of each period of the historiometric cycle show, according to Professor Tchijevsky, a morthological identity of all historical cycles; i.e., the same universal sequence of the behavior of active human masses in every cycle.

Undoubtedly, the actual historical events are much more complicated than they are schematically presented here; but mainly due to this schematization and simplification which are to be considered, according to Professor Tchijevsky, as preliminary, we are able to proceed in the objective study of this question.

The changes in the mode of behavior of the masses are especially conspicuous in the development of prolonged historical events.

The number of historical events, and more so, the intensity of their development has a tendency to follow in the detail the changes of the curve of sunspot activity; but it occurs sometimes that the maxima of human activities are attained shortly before the sunspot maxima, or they somewhat lag behind these maxima.

## IV THE INFLUENCE OF GEO-PHYSICAL AND COSMIC FACTORS ON THE BEHAVIOR OF COLLECTIVES AND INDIVIDUALS

It was also necessary to give an explanation of the regular sequences in the universal human activities from the standpoint of contemporary bio-physics. But first, the question should be solved: Is the influence of the sun's activity upon the centers of man's nervous system direct or indirect; i.e., through such factors (for example) as famine following a drought as a result of the sun's activity.

The researches made proved that such factors often coincide with the development of the cycle, but never can

be called predominant or indispensable to its development. (*) This is obvious from the fact that every century had the same number of concentrations of historical events and that the events took place simultaneously in different parts of the world.

If the development of historical events were left by itself, no definite period in its regular fluctuations nor simultaneous advent of it over the entire world, could ever be observed.

Therefore, we must assume that there exists a powerful factor outside our globe, which governs the development of events in human societies and synchronizes them with the sun's activity; and thus, we must also assume that the electrical energy of the sun is the super-terrestrial factor which influences historical processes.

The potential of the atmospheric electricity is always changing under different factors of the earth; temperature, humidity of atmosphere, amount of sunlight received, radiation of the earth itself, etc., all of which depend upon the amount of emitted sun energy.

These fluctuations are felt by human nervous systems, especially if they are sensitive.

Often these fluctuations pass unnoticed by calloused and strong natures, but even these natures re-act to the more pronounced fluctuations, causing in them a state of nervous tonus sometimes called, "change of humor" with no evident cause.

Professor Tchijevsky further refers to many authors and cites a great number of opinions, in confirmation of the aforesaid. Some of the names are given below: Herbert Spencer (1820–1903); the Russian Physiologist Professor Pavloff; the Russian Meteorologist Professor Klossovsky (in his "Physical Life of Our Planet according toContemporary Science"); Arrhenius (in "The Influence of Cosmic Factors on the Physiologic Functions"); Fits-Roy, Orloff, Dr. Dexter, Leman, Pedersen, Lombroso.

The English Psychiatrist Maudsley says, "We vibrate in tune with individual influences of the sky and earth, which cannot be measured by contemporary science." The French Astronomer Nordmann considers that even the smallest fluctuations of the outer world of matter must exert their influence upon the general condition of man's nervous system and produce changes in his psychic activities. Nordmann sees, in the laboratory electroscope, one of the most powerful forces of the future state, the regulator of the social regime, of the prosperity of the country and the behavior of the citizens.

And not only human beings respond to the fluctuations of the surrounding matter, but even animals and plants (French Entomologist Fabre).

The nervous activity is being studied at present in some laboratories with the help of physical and chemical methods. The works of great American and European scientists such as J. Loeb, W. Nernst, P. Lazareff-Director of the Institute of Biology in Moscow, show that the basis of nervous activity lies in the physical-chemical process.

The same is found in the process of thought, as stated in Biophysics and Ionic theories by Lazareff.

*NOTE: Owing to lack of space, only those few names and sources are cited from the many enumerations given by Professor Tchijevsky.*

During the last War, the author made very interesting observations: the appearance of large sunspots was immediately followed by increased activities on different battle fronts simultaneously. The first observation was made in the middle of June 1915 when a large group of sunspots crossed the central meridian of the sun, and when the aurora borealis were exceedingly powerful in North American and Northern Europe, and magnetic storms were exceptionally strong and interfered with telegraph work. At the time of these phenomena, the hardest and bloodiest fights of the war were being fought by Germans, Russians, Austrians, Serbians, French and English.

These observations were the author's first impulse to begin his present research work.

The Russian Revolution of February and October 1917, and the Revolutions in Germany and Austria also followed an exceptionally powerful rising of sunspots.

There are indications that at the time of the maximum of the number of sunspots, the number of psychomotoric excesses greatly increases. For the purpose of finding out this dependence, the author made a special research which showed that the dates of the greatest agitations in the masses coincided in time with the dates of great perturbations in the matter of the sun.

These coincidences, surprising in their significance, give such an amount of probability to the whole theory, that the author thinks they justify his assiduous and painstaking study of the subject;

Concluding this chapter, Professor Tchijevsky says that historical events develop by a certain series of jolts which are the results of fluctuations in the sunspot development process.

He also says that the study of social events in correlation with geophysical and cosmic events must result in illucidating the general law which governs mass activities of men and to make possible a scientific foundation for the study of laws of human societies.

*C. Lombroso & R. Laschi "Le Crime Politique." pp. 113, 122, etc.

## V PROSPECTS AND CONCLUSIONS

The changes in the lives of individuals also depend upon the changes in the periodical activity of the sun; as an example, Professor Tchijevsky mentions the life of Napoleon. The maxima and minima of Napoleon's activities correspond to the same periods in the sunspot activity. Thus, 1809–1811, minimum of sunspot activity (Wolf) and no campaigns; 1804 maximum of sunspots and the greatest campaigns of Napoleon with the title of emperor; 1816 again sunspot maximum and a new period of war which brought Napoleon to St. Helena.

In making his conclusions, Professor Tchijevsky states that his researches were merely the first efforts in this direction and that only the united efforts of men of science, in the development of the theory of correlation between the sun's activity and human activities, can give a stable foundation to this new branch of science which he believes will have such an important bearing on the future of humanity.

As a result of his theories, Professor Tchijevsky forecasts for the years 1927–1929, when the 11-year period of sunspot activity attains its maximum and when this maximum will coincide with the maxima of two other period of sixty years (Young) and thirty-five years (Bruckner, Lockyer), a great human activity of the highest historical importance which may again change the political chart of the world as was the result of a similar maximum in 1870.

The theory developed by the author, relating to the dependence of behavior of the masses upon the cosmic influence, is the deduction from the main principles of contemporary biophysics and can serve in a certain way as a confirmation of these principles.

Biophysics makes an assumption that the entire organism of man must be under the effect of powerful cosmic and geophysical factors.

The different events of the universal human history, in the light of the theory of Professor Tchijevsky, assume a new inner meaning and importance: they do not take place arbitrarily but are subordinate to physical laws of the physical world surrounding us. They can originate only when all the complicated politico-economic and other factors in humanity, with the physical factors of the world of inorganic nature, will favor them.

Due to the time development of historical events under control of certain physical laws, any fact in the life of separate human societies or in international life of humanity can be explained, and this will bring History to the level of the exact sciences ruled by definite laws. Professor Tchijevsky foresees that, in the near future, History and Sociology will have a system of measuring units.

Step by step, the exact sciences begin to penetrate the chaos of history, to measure it with identical time units and explain events which took place in remote times. Thus History is being changed into a science of the living, the necessary and the near; this new aspect revives events which seemed long dead, and gives clear explanation to them as well as to historical personalities and their doings.

The elemental changes of the processes in the sun are followed by a certain change in material processes in the organs of man's higher nervous activity, and these processes violate the general line of behavior of humanity, which the author calls, "the historical process."

Then arises the question: are we not in the slavery of the sun and its electrical power? The answer is, Yes, in a certain way we are, but this yoke is only comparative, as we can direct our activities in the right way. The sun does not oblige us to do this or that; it only obliges us to do *something*. But humanity follows the way of least resistance and drowns itself in oceans of its own blood.

As has already been shown by the author, the maximum of sunspot activity favors the excitability and uniting of the masses for attaining a certain general necessity brought forward by economic or other causes, and bring forth mass actions and leaders. But these acts are not inevitable; all depends upon previous events. For example; if a war is already in progress from the previous period, the general excitement may assume the form of ardor for peace at any price. The essential point of the third period (maximum) is the mass determination for attaining a sole result.

History knows many good examples of mass excitements in the period of maximum which had nothing in common with the sanguinary events; such as, some religious movements; pilgrimages; growing democracy; localization of public attention to legal processes, reforms, engineering projects; etc.

This gives origin to an idealistic hope that the culture of future generations will find ways to a humanitarian use of the mass upheaval, by means of preliminary propaganda for some undertaking of great public interest and importance which is to be completed in the period of the maximum of excitability. Then scientific expeditions, sport competitions, building of stupendous structures (bridges, canals, railroads, whole towns, etc.), collective theatrical art, collective creative art with mass participation, would occupy the place of human bloody slaughter.

Таб. 1. Опыт построения историометрической таблицы (всех народов с V в. до Р. Хр. по XX в.)

| №№ | V век до Р. Хр. (B.C.). | | IV. | | III. | |
|---|---|---|---|---|---|---|
| №№ | Равные 11-летние периоды. | Историометрические циклы. | Равные 11-летние периоды. | Историометрические циклы. | Равные 11-летние периоды. | Историометрические циклы. |
| | (500) | | | | | |
| 1 | (489) | 494—487 | (389) | 396—390 | (289) | 286—278 |
| 2 | (478) | 480—479 | (378) | 382—376 | (278) | 275—271 |
| 3 | (467) | 470—460 | (367) | 371—362 | (267) | 266—260 |
| 4 | (456) | 457—453 | (356) | 355—351 | (256) | 256—249 |
| 5 | (445) | 450—447 | (345) | 344—338 | (245) | 243—237 |
| 6 | (434) | 435—431 | (334) | 335—326 | (234) | 230—227 |
| 7 | (423) | 428—422 | (323) | 323—321 | (223) | 225—215 |
| 8 | (412) | 418—410 | (312) | 311—307 | (212) | 212—206 |
| 9 | (401) | 407—399 | (301) | 301—295 | (201) | 202—195 |
| | II. | | III. | | IV. | |
| №№ | Равные 11-летние периоды. | Историометрические циклы. | Равные 11-летние периоды. | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. |
| 1 | (101) | 101—106 | (201) | 197—201 | 301 ● | 303 |
| 2 | (112) | 114—116 | (212) | 209—216 | 311 | 311—314 |
| 3 | (123) | | (223) | 221—226 | 322 | 323 |
| 4 | (134) | 132 | (234) | 231—234 | 342 | 340 |
| 5 | (145) | 147 | (245) | 242 | 354 ● | 351 |
| 6 | (156) | 162—167 | (256) | 248—251 | 359 | 357—363 |
| 7 | (167) | 173 } | (267) | 260—269 | 374 ● | 371—378 |
| 8 | (178) | 178 } | (278) | 272—277(285) | 388 | 383—391 |
| 9 | 188 | 181 | (289) | 295—296 | 395 | 394—397 |
| | VIII. | | IX. | | X. | |
| №№ | Деят. солнца по ист. данным | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. |
| 1 | (704) | | (797) | 798—802 | (896) | 899—904 |
| 2 | (712) | 711—712 | 807 | 808—812 | 905 | 907—915 |
| 3 | (723) | 717—720 | (818) | 823—824 | 919—930 (?) | 921—929 |
| 4 | (734) | 732—733 | 830 | 832—833 | 940 | 937—941 |
| 5 | 745 | 737—740 | 840 ● | 841—846 | (948) | 944—947 |
| 6 | (755) | 752—759 | 848 (?) | 856—859 | 956 | 951—955 |
| 7 | 765 | — | 860 | 865 | (966) | 961—969 |
| 8 | 778 | 772—782 | 874 | 875—878 | 974 | 961—969 |
| 9 | 786 | 787—793 | (885) | 886—891 | 979—993 (?) | 973—978 |
| | XIV. | | XV. | | XVI. | |
| №№ | Деят. солнца по ист. данным | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. |
| 1 | 1307 | 1303—1307 | 1402 | 1398—1403 | (1500) | 1499—1502 |
| 2 | (1312) | 1311—1315 | (1403) | 1408—1415 | (1510) | 1509—1512 |
| 3 | 1325 | 1322—1330 | (1424) | 1419—1422 | 1520 1527 | 1517—1528 |
| 4 | (1336) | 1337—1340 | 1431 | 1427—1434 | 1537 | 1531—1536;1542 |
| 5 | 1353 ? | 1345—1353 | 1446 | 1443—1456 | 1551 ● | 1549—1553 |
| 6 | 1365 | 1356—1365 | 1461 | 1458—1464 | 1560 ● | 1558—1563 |
| 7 | 1372 ● | 1368—1372 | (1472) | 1469—1471 | 1572 ● | 1566—1573 |
| 8 | 1383 | 1377—1385 | (1483) | 1476—1486 | 1581 ● | 1578—1582 |
| 9 | (1394) | 1388—1396 | 1490 | 1489—1495 | 1588 ● | 1585—1592 |

Table 1: REPRODUCTION OF TCHIJEVSKY'S TABLE.

COLUMN HEADINGS FOR EACH CENTURY READ AS FOLLOWS: FIRST COLUMN, V CENTURY B.C. THROUGH III CENTURY A.D. "EQUAL 11-YEAR PERIODS." FIRST COLUMN, IV CENTURY A.D. THROUGH XVI CENTURY A.D. "SUN'S ACTIVITY FROM HISTORIC DATA." FIRST COLUMN, XVII, XVIII, AND XIX CENTURIES, "SUN'S ACTIVITY, MAXIMUM AND MINIMUM."

Historiometrical table during the period from V B. C. till XX A. D. Experiment of its construction.

| II. | | I. | | I век. по Р. Хр. (A. D.). | |
|---|---|---|---|---|---|
| Равные 11-летние периоды. | Историометрические циклы. | Равные 11-летние периоды. | Историометрические циклы. | Равные 11-летние периоды. | Историометрические циклы. |
| (189) | 191—189 | (89) | 90—82 | (1) | 6—9 |
| (178) | 186—183 | (78) | 78—72 | (12) | 14—19 |
| (167) | 171—165 | (67) | 69—62 | (23) | —— |
| (156) | 156 | (56) | 58—51 | (34) | —— |
| (145) | 149—143 | (45) | 49—41 | (45) | 42—45 |
| (134) | 135—133 | (34) | 33—31 | (56) | 58—59 |
| (123) | 126—118 | (23) | 27—25 | (67) | 64—70 |
| (112) | 113—108 | (12) | 16—12 | (78) | 78—85 |
| (101) | 105—101 | (1) | | (89) | 91 |
| **V.** | | **VI.** | | **VII.** | |
| Деят. солнца по ист. данным. | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. |
| 401 | 401—406 | 502 | 507—510 | 603 | 602—604 |
| (412) | 408—415 | (513) | 515—517 | (614) | 614—618 |
| (423) | 419—420 | 535 | 529—536 | 626 | 622—628 |
| (434) | 429—433 | (546) | 539—543 | (634) | 633 637 |
| 450 ● | 448—455 | (557) | 551—555 | (645) | 641—642 |
| (467) | 465 | 566 ● | 566—568 | (656) | 653 |
| (478) | 476 | 577 ● | 575 | (667) | 668—670 |
| (489) | 486—493 | 585 ● | 581 | (678) | 681—187 |
| (500) | 496 | (596) | — | (689) | 695—697 |
| **XI** | | **XII.** | | **XIII.** | |
| Деят. солнца по ист. данным | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. | Деят. солнца по ист. данным. | Историометрические циклы. |
| 1005 | 1000—1004 | 1104 ● | 1103—1106 | 1202 ● | 1201—1205 |
| 1014 | 1012—1015 | 1118 ● | 1113—1119 | (1213) | 1211—1216 |
| (1025) | 1026 1030 | 1129 ● | 1124—1132 | (1221) | 1223—1228 |
| 1039 | 1035—1041 | 1137 ● | 1135—1139 | 1238—1242 { | 1234—1236 |
| (1050) | 1044—1052 | 1145 | 1143—1147 | | 1239—1246 |
| (1061) | 1056—1059 | 1157 | 1151—1162 | (1253) | 1255—1256 |
| (1072) | 1068—1073 | (1168) | 1166—1176 | 1269 | 1265 1270 |
| 1078 ● | 1075—1085 | 1185 ● | 1182—1188 | 1276 | 1275—1282 |
| 1096 | 1093—1400 | 1193 | 1191—1197 | 1292 | 1285—1293 |
| **XVII** | | **XVIII.** | | **XIX.** | |
| Деят. солнца. Max. Min. | Историометрические циклы. | Деят. солнца Max Min. | Историометрические циклы. | Деят. солнца. Max. Min. | Историометрические циклы. |
| 1605 ● 1610.8 | 1596—1607 | 1705.5 1712.0 | 1709—1711 | 1805.2 1810.6 | 1797—1809 |
| 1615.8 1619.0 | 1612—1618 | 1718.2 1723.5 | 1714—1722 | 1816.4 1823.3 | 1812—1822 |
| 1626.0 1634.0 | 1624—1632 | 1727.5 1734.0 | 1728—1734 | 1829.9 1833.9 | 1824—1833 |
| 1639.5 1645.0 | 1635—1643 | 1738.7 1745.0 | 1737— | 1837.2 1843.5 | 1835—1843 |
| 1649.0 1655.0 | 1647—1657 | 1750.3 1755.2 | —1750 | 1848.1 1856.0 | 1845—1856 |
| 1660.0 1666.0 | 1658—1664 | 1761.5 1766.5 | 1756—1764 | 1860.1 1867.2 | 1857—1868 |
| 1675.0 1679.0 | 1666—1677 | 1769.7 1775.6 | 1768—1775 | 1870.6 1878.9 | 1870—1877 |
| 1685.0 1689.5 | 1687—1689 | 1778.4 1784.7 | 1778—1781 | 1883.9 1889.6 | 1879—1888 |
| 1693.0 1698.0 | 1690—1698 | 1788.1 1798.3 | 1787—1794 | 1894.1 1901.7 | 1891—1900 |

SECOND COLUMN THROUGHOUT THE TABLE READS, "HISTORIOMETRICAL CYCLE."

HEAVY FIGURES SHOW THE PROBABLE DATES OF SUNSPOT MAXIMA: HEAVY DOTS SHOW THE MORE RELIABLE ONES (AS KNOWN IN 1924). FROM THE XVII CENTURY TO THE XIX CENTURY THE DATES OF SUNSPOT MAXIMA AND SUNSPOT MINIMA ARE TAKEN FROM ASTRONOMICAL AND TELESCOPIC OBSERVATIONS.

Ed.

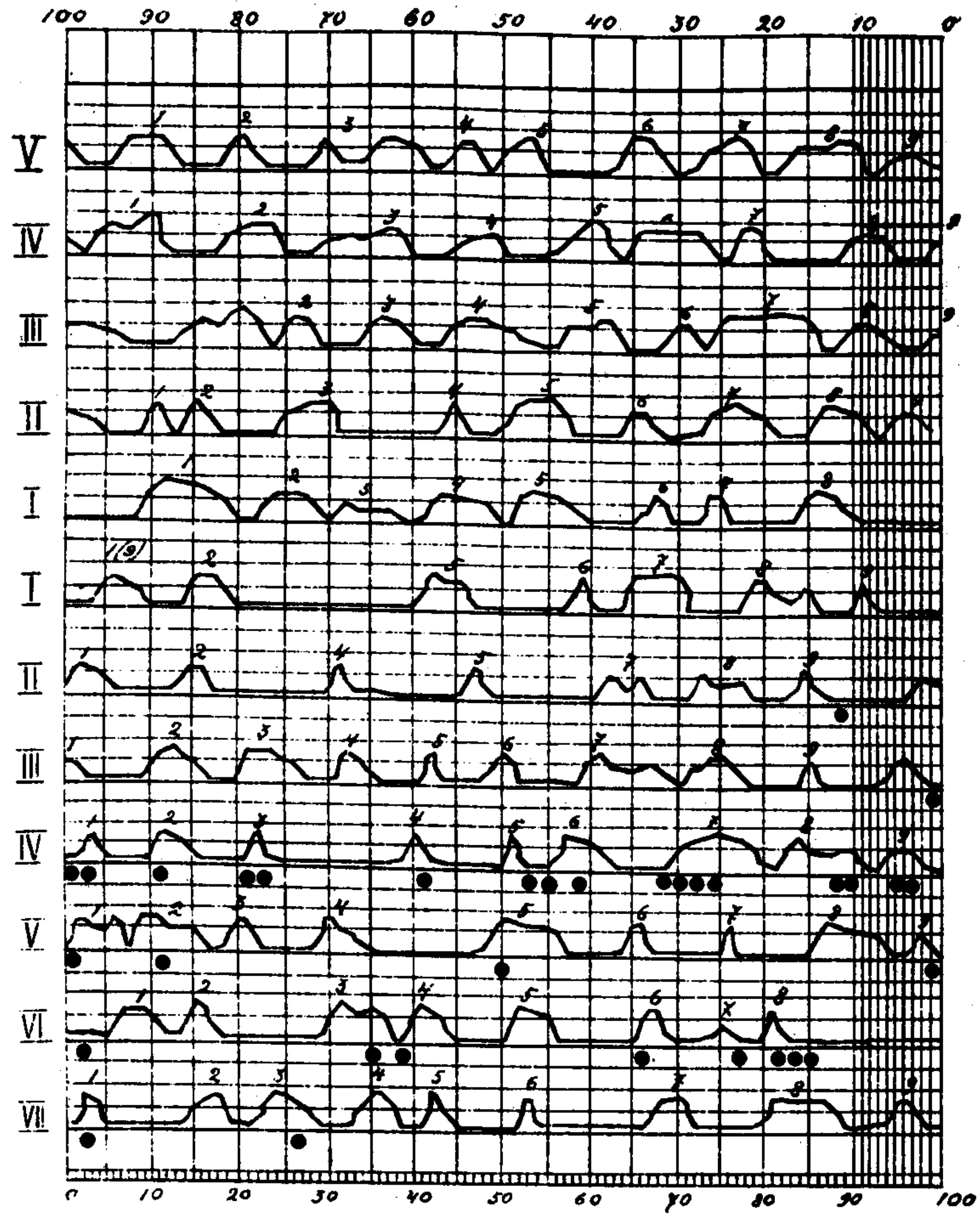
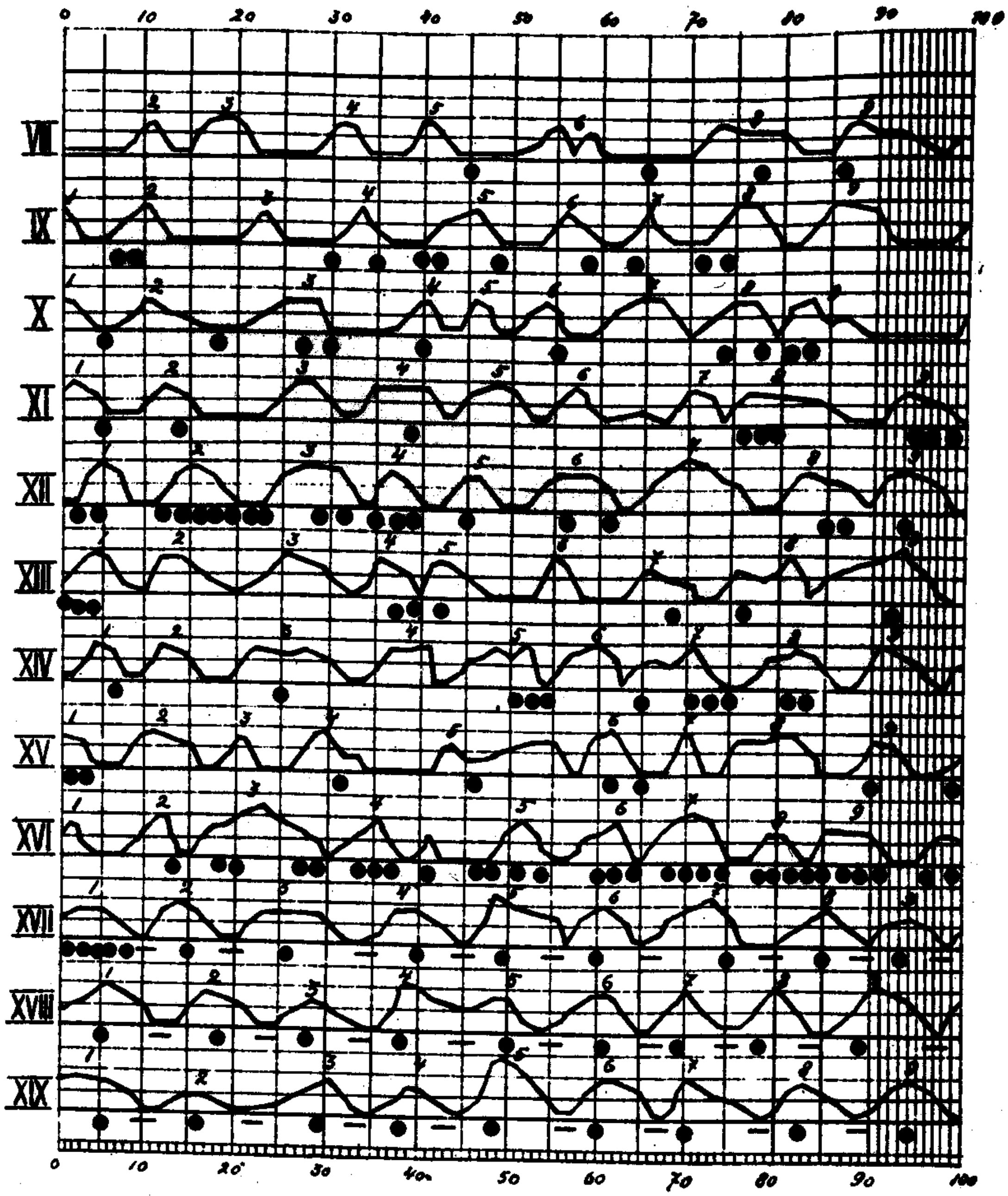
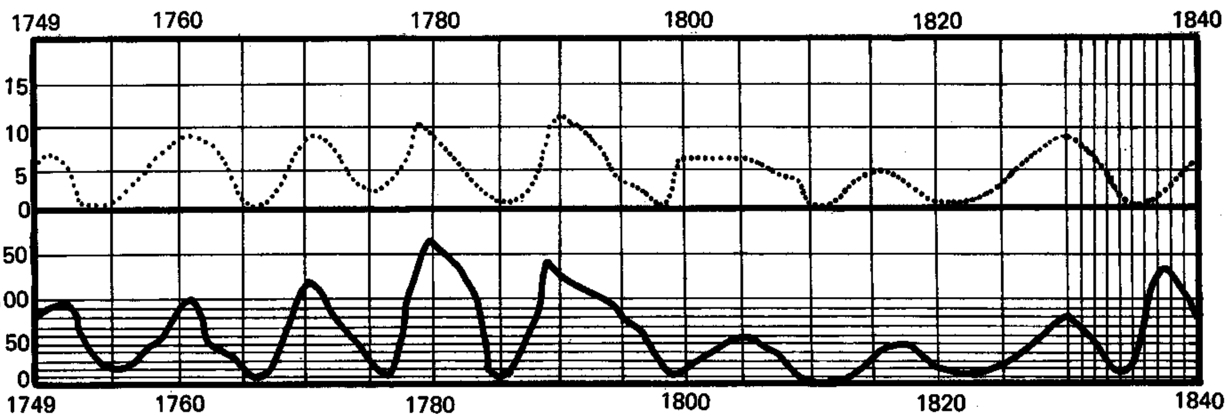


Fig. 2 and Fig. 3: THE FLUCTUATIONS' MEAN CURVES OF THE UNIVERSAL HISTORICAL PROCESS ON ALL THE SURFACE OF THE EARTH DURING THE PERIOD FROM V CENTURY B.C. TILL XX CENTURY A.D. ALONG THE AXIS ABSCISSAE ARE MARKED THE YEARS. ALONG THE AXIS ORDINATES—THE QUANTITY OF IMPORTANT HISTORICAL EVENTS. DOTS MARK THE PRETELESCOPIC AND LATER—ASTRONOMICAL DATA OF THE SUNSPOT MAXIMUM. HYPHENS MARK ITS MINIMUM.



0
10
20
30
40
50
60
70
80
90
100
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX



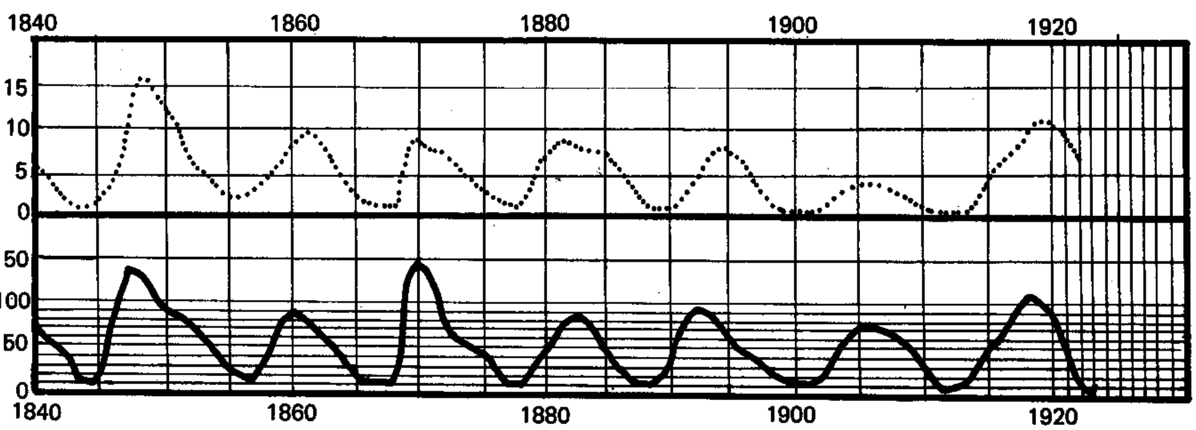




Fig. 4: PARALLELISM OF THE CURVES OF SUNSPOT ACTIVITY (BELOW) AND THE UNIVERSAL HUMAN MILITARY. POLITICAL ACTIVITY (ABOVE) FROM 1749 TILL 1922.

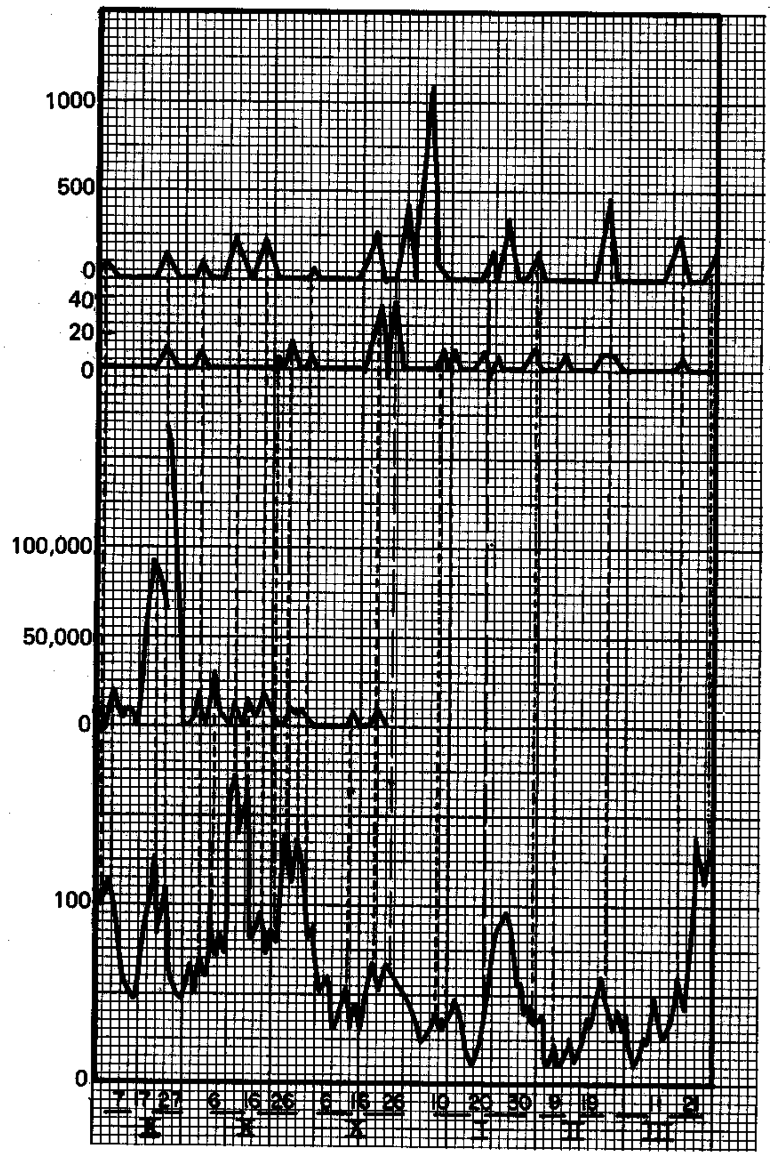



Fig. 5: COINCIDENCE OF THE EPISODIC LEAPS IN THE SUNSPOT ACTIVITY (LOWER CURVE) AND THE OUTBURSTS OF REVOLUTIONARY ACTIVITY IN THE MASSES ON THE TERRITORY OF RUSSIA DURING THE PERIOD FROM 1 OCTOBER 1905 UNTIL 1 APRIL 1906 (STRIKES AND MEETINGS: BOMBS AND ATTEMPTS: IMMEDIATE REPRESSION).

Ancient Aurorae
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# Ancient Aurorae

*By Richard Stothers**

ANCIENT OBSERVATIONS of the aurora borealis were perforce made visually and in the Western world were recorded almost exclusively by peoples of the Mediterranean basin. It will be useful initially to recapitulate the easily visible features of modern aurorae so that the historical ones can be discussed. Three basic forms occur: (1) rayless forms, such as arcs, bands, and glows; (2) rayed forms, such as draperies and coronae; and (3) flaming aurorae. A rapid pulsation or wavelike motion is sometimes also observed. At low geomagnetic latitudes the usual forms are quite simple, showing little or no motion; the color most frequently observed is red or yellowish white; and the average incidence of visible aurorae is about one per decade, although in Italy the incidence is a few times greater than in Greece. Aurorae at these latitudes do not often appear far from the time of maximum in the eleven-year solar activity cycle.[1] Thus, it is only to be expected that ancient auroral reports must be vague and few in number and must present considerable difficulties of interpretation.

It is my intention in the present paper to trace the history of auroral studies in the ancient Western world, to comment on the partial modern rediscovery of this record, and to propose a classification scheme for ancient aurorae. A new and fully documented catalogue of ancient auroral reports has been compiled for this purpose and will be discussed statistically for whatever implications can be drawn concerning auroral activity in the distant past.

## ANCIENT KNOWLEDGE OF AURORAE

The earliest Greek sky myths are possible repositories of information on prehistoric auroral observations.[2] For example, the *Theogony,* a prescientific creation story, records lurid details like "flaming heavens," "fiery sky dragons," and even a "rain of blood."[3] These notions must have persisted for centuries.

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[1]Carl Störmer, *The Polar Aurora* (Oxford: Clarendon Press, 1955).

[2]See J. J. D. de Mairan, *Traité physique et historique de l'aurore boréale* (2nd ed., Paris: Imprimerie Royale, 1754), pp. 462–463 (1st ed. 1733).

[3]Hesiod, *Theogony* 183–184, 689–693, 824–828. Nonnus, many centuries later, interpreted Hesiod's myth of Typhon in terms of "comets," "fiery beams," and "flaming exhalations" (*Dionysiaca* II 198–200, 482–492, 515–516; compare Pliny, *Naturalis historia* II 91; Avienus in Servius, *In Vergilii Aeneadum, ad* X 272). Homer (*Iliad* XI 53–54, XVI 458–459) mentions two mythological "rains of blood," which, however, his later commentator Heraclitus (*Homeric Allegories* 42) interpreted as simply a fall of red-colored raindrops, and the Scholiast (*ad* XI 53–54) as a downpour of human blood that had previously evaporated. Later writers of epic and tragedy also occasionally referred to early "blood rains." Of further interest in connection with possible aurorae are the myth of a "milk rain" when Hera generated the Milky Way (see esp. *Geoponica* XI 19) and the myth of Phaëthon's sky ride, which was interpreted in an explicitly allegorical sense as, i.a., "a mass of sky fire" (pseudo-Aristotle, *De mundo* 400a30–32; Lucretius, *De rerum natura* V 406–408; Philostratus, *Imagines* I 11), "a fiery exhalation" (Domninus in Proclus, *In Platonis Timaeum, ad* 22) and "a comet" (Proclus, *ad* 22; Philoponus, *In Aristotelis Meteorologica, ad* 345a13; Olympiodorus, *In Aristotelis Meteorologica, ad* 345a11). Other mythological "comets" and "torches" are of less interest here. In biblical exegesis, Philo Judaeus (*Quaestiones et solutiones in Genesin* III 14–15) interpreted Genesis 15:17 in terms of Aristotle's "fiery exhalations."

When serious Greek inquiry into nature began in the sixth century B.C., speculation about the origin of "comets" (aurorae?) seems to have been widespread.[4] Ideas that may well encompass auroral phenomena include: "inflammable exhalations from the earth" (Anaximenes) and "moving accumulations of burning clouds" (Xenophanes). In the next century Hippocrates of Chios and his student Aeschylus developed their idea of "reflected sunlight," while in the fourth century Metrodorus of Chios and Heraclides of Pontus favored "illuminated clouds," although Aristotle adhered more closely to the older, sixth-century views. The earliest known Greek account of what is now accepted to be an actual auroral display dates, in its original form, from the fifth century B.C. (probably from the lost treatise of Anaxagoras), and is preserved as a fragment in Plutarch:

> For seventy-five days continually, there was seen in the heavens a fiery body of vast size, as if it had been a flaming cloud, not resting in one place, but moving along with intricate and irregular motions, so that fiery fragments, broken from it by its plunging and erratic course, were carried in all directions and flashed fire, just as shooting stars do.[5]

This event is known to have occurred in 467 (or 468) B.C.

Whatever its antecedents were, the first reliable "scientific" description of an auroral display is generally acknowledged to be that of Aristotle, who wrote (c. 330 B.C.):

> Sometimes on a clear night a number of appearances can be seen taking shape in the sky, such as "chasms," "trenches" and blood-red colours. These again have the same cause. For we have shown that the upper air condenses and takes fire and that its combustion sometimes produces the appearance of a burning fire. . . . The cause of the brief duration of these phenomena is that the condensation lasts for a short time only. Chasms have an appearance of depth because the light breaks out from a dark blue or black background.[6]

Aristotle argues that reflection and attenuation of the fiery light as it passes through the denser, lower air contribute to producing the observed colors, and he clearly implies that the large angular extent and speed of the phenomena confirm their sublunary origin. In another place Aristotle also comments that if the inflammable substance in the sky "extends both lengthwise and breadthwise we often see a burning flame of the kind one sees when stubble is being burnt on ploughland." These remarks could have been precipitated by the spectacular sky displays of 349 and 344 B.C. seen in Greece; it is not necessary to suppose that Aristotle must have been in Macedonia to have seen an aurora.[7]

[4]Aëtius, *Placita* III 2 (Stobaeus, *Eclogae* I 28.1); Hippolytus, *Refutatio* I 6–8; Scholiast to Aratus, *Phaenomena, ad* 1091. An early 6th-century Persian aurora may be recorded in Xenophon, *Cyropaedia* IV 2.15; cf. Dio Chrysostom, *Orations* 36.40 (Zoroastrian aurora?) and Exodus 19:16–20, 20:18, 24:15–18.

[5]Daimachus (4th century B.C.?) in Plutarch, *Lysander* XII 4, trans. Bernadotte Perrin, *Plutarch's Lives* (Cambridge, Mass.: Harvard University Press, 1916). The frequent auroral interpretation of this passage has been most recently defended by P. J. Bicknell, "Did Anaxagoras Observe a Sunspot in 467 B.C.?" *Isis,* 1968, *59*:87–90.

[6]Aristotle, *Meteorologica* 342a34–342b16, trans. H. D. P. Lee, *Aristotle: Meteorologica* (Cambridge, Mass.: Harvard University Press, 1952). W. D. Ross, in *The Works of Aristotle* (Oxford: Clarendon Press, 1931), Vol. III, footnote *ad loc.,* supposes that the chasms are due to cloud coloration. They have also been attributed to the light-stripes that sometimes appear during bright nights (nocturnal airglow) by S. M. Silverman, "On the 'Chasms' of Aristotle and Pliny," *Journal of Atmospheric and Terrestial Physics,* 1962, *24*: 1108–1109. However, the longstanding (de Mairan 1733) auroral interpretation has been upheld, in my opinion definitively, by Francis Celoria, in "The Alleged Dark Segment in Aurora Borealis Displays," *Journal of the British Astronomical Association,* 1968, *78*: 129–132; see also J. L. Ideler, *Meteorologia veterum Graecorum et Romanorum* (Berlin: Nauck, 1832), pp. 49–54.

[7]Aristotle, *Meteorologica* 341b25–27. The display of 349 is recorded in Pliny (*Naturalis historia* II 97) and that of 344 in Plutarch (*Timoleon* VIII 5–7).

Heraclides of Pontus, an associate of Aristotle's, was possibly the first author to discriminate critically between "comets" and "beams, pillars, and all other manifestations of this kind,"[8] although Anaxagoras had already described the object of 467 as a "beam," according to a certain Charmander cited by Seneca, and although Pliny knew, from an unidentified source, about another "beam" seen in Greece in 394.[9] It is likely that Heraclides actually witnessed the "beam" of 373 (or 372), which touched off much speculation by natural philosophers of that time.[10] Thus, by the late fourth century B.C. all the basic features of prominent aurorae visible from low latitudes had been described and speculated upon by Greek natural philosophers.

In the Roman world, legendary memories of a "blood rain" during the reign of King Romulus are preserved by Plutarch.[11] However, the earliest datable Roman aurorae comprise a distinct cluster of events spanning the approximate years 464–459 B.C. They are recorded in the histories of Livy and Dionysius of Halicarnassus. A typical report simply states that "the sky was seen to blaze with numerous fires."[12] A large lacuna in our subsequent record of Roman aurorae extends down to the year 223 B.C. But after that time reports of aurorae are fairly frequent until late in the first century A.D., after which they all but vanish for the next three centuries.

Probably all the Italian reports before the first century B.C. appeared originally in the annual commentaries of the Pontifex Maximus, the source of most of the Roman historical tradition.[13] But these reports of celestial prodigies to be expiated are too brief and naïve to be considered "scientific." In fact, the earliest (and best) surviving examples of Roman scientific writing on aurorae date from the first century A.D. and are due to Manilius, Seneca, and Pliny, who relied either directly or indirectly on earlier Greek treatises for theory but embellished their texts with illustrations drawn from their own experience and from previous Roman writings. Here is a selection of what Seneca had to say on the subject:

> It is time to consider, briefly, other atmospheric fires, of which there are various forms. . . . There are "trenches": within a surrounding corona there is a great gap in the sky like a hole dug in a circle. There are "barrels": an enormous round mass of fire, like a barrel, either darts by or blazes in one place. There are "chasms": some area of the sky settles and,

[8] Aëtius, *Placita* III 2 (Stobaeus, *Eclogae* I 28.1).

[9] Seneca, *Naturales quaestiones* VII 5.3; Pliny, *Naturalis historia* II 96. Pliny may actually be referring to the "beam" of 373.

[10] See Diodorus Siculus, *Library of History* XV 50.2. Demetrius of Phalerum, in the generation after Heraclides, was another early writer on "beams" (Diogenes Laertius, *Vitae philosophorum* V 81; Achilles Tatius, *Isagoge ad Arati Phaenomena* 34). Aristotle never mentions "beams" but calls the objects of 467 and 373 "comets." On the other hand, he discusses "torches," of which some appear to be morphologically similar to "beams" (see *Meteorologica* 341b1–342b24). Other authors, however, have used the term λαμπάδες rather than Aristotle's δαλοί when referring to these beamlike "torches." But there exists a tradition that Aristotle himself did include "beams" among the "torches" and "comets" (pseudo-Aristotle, *De mundo* 392b4, 395b12; Seneca, *Naturales quaestiones* VII 5.4; Stobaeus, *Eclogae* I 34.2; Olympiodorus, *ad* 344a20). The interesting question of what influence on the early Greek philosophers might have been exerted by imported Chaldean cometary ideas and the related question of what dates should be assigned to the Greek cometographers Epigenes, Apollonius of Myndos, and Artemidorus of Parium are still moot; for differing views cf. Rudolf Hartmann, *De Senecae naturalium quaestionum libro septimo* (Monasterii Guestfalorum, 1911) and Paul Oltramare, *Sénèque: Questions naturelles* (Paris: Belles-Lettres, 1929). Other ancient categories of "comets" will not be discussed here since they have turned out to play no significant role in identifying datable aurorae. In any case, they seem to have been rarely seen toward the north (pseudo-Aristotle, 395b14–15).

[11] Plutarch, *Romulus* XXIV 1. Geoffrey of Monmouth (12th century), *Historia regum Britanniae* II 16, claims that a British "rain of blood" occurred at that time! Two possible aurorae in Vergil's *Aeneid* (VII 142–143, IX 20) are undoubtedly only literary inventions.

[12] Livy, *Ab urbe condita* III 5.14. See also Livy III 10.6; Dionysius of Halicarnassus, *Roman Antiquities* X 2.3. I have retained the traditional dates (which may be a few years too early).

[13] Cicero, *De oratore* II 12.52; Servius, *In Vergilii Aeneadum, ad* I 373; Macrobius, *Saturnalia* III 2.17.

> gaping in hiding—so to speak—sends out flame. The colors of all these are also very numerous: some are a very bright red, some a pale and light flame, some a white light, some flickering, some uniformly yellow and without outbursts or rays. . . . "Beams" and the rarely seen "barrels" . . . require a great mass of fire. The immensity of their spheres at times surpasses the size of the morning sun. Among these you may also include a phenomenon which we read about frequently in history: the sky seems to be on fire. Sometimes its glow is so high it appears to be actually among the stars. Sometimes it is so low that it gives the illusion of a fire some distance away. In the reign of Tiberius Caesar watchmen rushed to the aid of the colony at Ostia just as though it were ablaze, since throughout most of the night there had been a glow in the sky, dull, as of a thick smoky fire. Concerning these phenomena no one doubts that they have the flame which they show; there is a definite substance to them.[14]

The practice followed by all known post-Aristotelian writers on aurorae remained the same down to the end of classical antiquity.[15] It is fair to say that despite the steady accumulation of auroral observations, no real progress in theory or even in recognition of the common elements of auroral phenomena was made after the fourth century B.C. What had been definitely established, thanks largely to the work of Aristotle, was that the auroral light arises from the atmosphere and is emitted light rather than reflected sunlight (although a few ancient writers persisted in assigning the "beams" and "pillars" to the aether). Since the tools necessary for further progress, such as the spectroscope and suitable northern observatories,[16] were not yet available, speculation and analogy became the substitutes for a more scientific approach.

## MODERN CATALOGUES

The modern phase of the study of ancient aurorae began in 1733 with the publication of Jean Jacques de Mairan's now classic textbook *Traité physique et historique de l'aurore boréale*. He and many of his successors tried to identify possible aurorae in the works of the better-known classical authors. In an effort to consolidate the subject, four authors published catalogues of ancient aurorae: Frobesius in 1739, Fritz in 1873, Schove in 1948, and Link in 1962.[17] Unfortunately, these catalogues

[14] Seneca, *Naturales quaestiones* I 14.1–15.5, trans. T. H. Corcoran, *Seneca: Naturales quaestiones* (Cambridge, Mass.: Harvard University Press, 1971). In Corcoran's translation I have introduced alternate renderings of a few of the technical words. It is unfortunate that the "sky fire" of Tiberius' reign (A.D. 14–37) cannot be more precisely dated.

[15] A chronological arrangement of these authors and a comparison of their opinions concerning fiery sky phenomena can be found, e.g., in Hartmann, *De Senecae,* and in Johannes Hemsing, *De Senecae naturalium quaestionum libro primo* (Monasterii Guestfalorum, 1913).

[16] Few ancient reports of aurorae in northern countries have come down to us. Three rather far-fetched examples have been suggested by S. Günther, "Das Polarlicht im Altertum," *Beiträge zur Geophysik,* 1903, *6*:98–107. As alternative explanations, I suggest that the northern "sea-lungs" of Pytheas of Marseilles (Strabo, *Geography* II 4.1) can be more easily interpreted as sea ice; the northern "rays" of Tacitus (*Germania* 45) as the permanent sunbeams on a summer night at high latitudes; and the northern "demons" of Plutarch (*De facie quae in orbe lunae apparet* 941F; cf. Pedo in the Elder Seneca, *Suasoriae* I 15) as indefinable in any context. Of uncertain nature also is the "falling sky" that the Celts feared (Strabo VII 3.8; Arrian, *Anabasis Alexandri* I 4.8). However, a good description of an aurora in Germany is couched in similar terms (Dio, *Roman History* LVI 24.3–4). Gallic aurorae are mentioned in the literature twice (Obsequens, *Prodigiorum liber* 38, 44); perhaps a third Gallic aurora is the same as the aforementioned German one, which seems to have extended as far south as the Alps.

[17] Johannes Nicolaus Frobesius, *Nova et antiqua luminis atque aurorae borealis spectacula* (Helmstadt: Weygandus, 1739); Hermann Fritz, *Verzeichniss beobachteter Polarlichter* (Vienna: Kaiserlichen Akademie der Wissenschaften, 1873); Derek Justin Schove, "Sunspots and Aurorae," *J. Brit. Astron. Ass.,* 1948, *58*: 178–190; František Link, "Observations et catalogue des aurores boréales apparues en occident de −626 à 1600," *Geofysikální Sborník,* 1962, No. 173, 1–96. Some aurorae are listed in the comet catalogue of Alexandre G. Pingré, *Cométographie* (Paris: Imprimerie Royale, 1783), Vol. I. Of no independent value

have turned out to be not only inaccurate but incomplete as well, chiefly because the compilers have drawn heavily and uncritically on several earlier collections of ancient prodigies, especially the vast collection made by the sixteenth-century scholar Lycosthenes.[18] Although Lycosthenes did not acknowledge his sources, the modern compilers have not bothered to find them out, except in a few obvious cases. Yet any of the ancient sources available to Lycosthenes must almost certainly be available to us today.

In order to illustrate the dangers of not resorting directly to the original literature (and, even then, dangers are not entirely to be avoided), I give the following four examples. The first refers to a prodigy listed by Lycosthenes that is reported in all four catalogues as the oldest aurora mentioned in classical literature. Lycosthenes writes tersely of "military spears burning in the sky late at night" (c. 503 B.C.). This prodigy can be traced to the *Roman Antiquities* of Dionysius of Halicarnassus, who gives further details that indicate an obvious case of static electricity playing on iron spearheads.[19] Lycosthenes also provides a second example: a manifestation of "sky warriors at Aegina" in the year 463 B.C. The original passage is due to Plutarch, who has skeptically described a vision of armed men leaving Aegina during the (daytime) battle of Salamis in 480 B.C.[20] Third among these examples is a report transmitted by the seventeenth-century scholar Nihusius that "the sky was ablaze for 70 days a little before the Peloponnesian war; whereupon Athens, after being pulled down to the tune of a flute, blazed up." The date is reported as 443 B.C., but the original passages are again found to be in Plutarch, and the date ought to be 467 (or 468) B.C.[21] Lastly, a passage quoted by the seventeenth-century scholar Vincentius runs: "burning clouds, falling like meteors from the sky, were seen by Alexander the Great in Egypt" (c. 332 B.C.). This fragment turns out to be an abstract from "Alexander's Letter to Aristotle," an undoubted forgery that is preserved in the Alexander Romance of pseudo-Callisthenes. The particular passage in question, even if it is based on fact, actually refers to a lightning storm near the borders of India.[22] Further examples from the published auroral catalogues would be superfluous; an entirely new catalogue is obviously needed, and it is provided below.

## A NEW CATALOGUE

Difficulties of interpretation of the primary sources themselves cause problems enough. Clement of Alexandria, a late writer, refers to a "pillar of fire" that was seen in Greece in 404 B.C. Since he says that it appeared during a stormy night, it is unlikely to have been an aurora.[23] When Alexander's army reportedly saw the sky blazing the night before their final battle with the Persians (331 B.C.), Quintus Curtius

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are the fanciful lists of ancient aurorae compiled by Tito Nicolini, "Il periodo medio dell'attività solare in relazione alle osservatazioni antiche e moderne," *Rendiconto dell' Accademia di Scienze Fisiche e Matematiche in Napoli* (Ser. 4), 1942, *12*:79–88; "Sull'andamento secolare dell'attività solare," *ibid.*, 1976, *43*:1–11.

[18] Conradus Lycosthenes, *Prodigiorum ac ostentorum chronicon* (Basel: Oporinus, 1552).

[19] Dionysius of Halicarnassus, *Roman Antiquities* V 46.2. The passage from Lycosthenes is quoted by Frobesius, Fritz, Schove, and Link.

[20] Plutarch, *Themistocles* XV 1; see also Herodotus, *Histories* VIII 84. The passage from Lycosthenes is quoted by Fritz and, in a wrongly translated form, by Schove.

[21] Plutarch, *Lysander* XII 4, XV 4. Nihusius is quoted by Frobesius and, in an abbreviated form, by Fritz and Schove.

[22] Pseudo-Callisthenes, *Historia Alexandri Magni* III 17 (Kroll 111.3.n.). See also the Latin version of Julius Valerius, *Res gestae Alexandri Macedonis* III 35; versions also exist in Syriac, Armenian, Ethiopic, and other languages. Vincentius is quoted by Frobesius and Link, and alluded to by Schove.

[23] Clement of Alexandria, *Stromata* I 24; cf. Exodus 13:21–22, 14:24.

later took this conflagration to have been a celestial prodigy rather than the campfires of the enemy or the brushfires caused by the enemy's scorched-earth policy.[24] I reject, with Plutarch, the first interpretation. Livy's report of "scattered fires in the sky followed by a huge torch blazing out" (203 B.C.) is best read as an intense meteor shower with one particularly bright meteoric fireball.[25] Although an inverted order of physical development is reported by Cassius Dio for the comet of 12 B.C., the nightly persistence of this comet as a "torch" seems to preclude its having been in reality an aurora.[26] Tacitus describes "fiery clouds" illuminating the Temple at Jerusalem (A.D. 65?), but Josephus' account of what is probably the same event implies some kind of static electrical phenomenon. The two accounts can be reconciled by assuming that an outbreak of St. Elmo's fire occurred inside the Temple during an intense lightning storm at night.[27] Apart from these specific examples, I also reject the following *classes* of phenomena: daytime lights of all kinds, lightning from a clear sky, fiery globes, new stars, sky armaments, sky ships, and burning seas.[28]

What, then, are the phenomena that can safely be regarded as auroral (at least in most instances)? A systematic search of the classical literature reveals that most of the probable aurorae divide themselves neatly into just a few categories. These divisions are based on certain described forms, which reflect the ancients' view of aurorae and do not necessarily conform to the modern divisions. Therefore, it seems best to retain the original categories, since the ancient practice of using invariably the same descriptive formulae in reporting celestial prodigies suggests that the same physical phenomena (whatever they may be) are being reported over the centuries. In the order of their probable association with aurorae, the categories are:

X. Chasm (χάσμα, *hiatus* or *discessus*).

SF. Sky fire (οὐρανὸς φλεγυρός, *caelum ardens*).

NS. Night sun (ἥλιος or φῶς νυκτός, *sol* or *lux noctu*).

BR. Blood rain (ψεκὰς αἱματώδης, *pluvia sanguinea*).[29]

MR. Milk rain (ψεκὰς γαλάκτινη, *pluvia lactea*).[30]

B. Beam (δοκίς, *trabs*).

P. Pillar (κίων, *columna*).

T. Aurora-like torch (λαμπάς, *fax*).

K. Aurora-like comet (κομήτης, *stella crinita*).

[24] Quintus Curtius, *Histories* IV 12.14; Plutarch, *Alexander* XXXI 4–5.

[25] Livy XXX 2.11.

[26] Dio, *Roman History* LIV 29.8.

[27] Tacitus, *Histories* V 13.2; Josephus, *Jewish War* VI 5.3. Josephus' more reliable account was much quoted by later compilers, both ancient and modern.

[28] P. Bicknell, in "Globus Ignis," *Le monde grec: hommages à Claire Préaux* (Brussels: University of Brussels Press, 1975), pp. 285–290, has argued that a small percentage of the reported "fiery globes" could be aurorae. The other rejected categories could also contain a small number of aurorae.

[29] Some authors, including Cicero (*De divinatione* II 58), have ill-advisedly regarded "blood rain" as being in all cases simply contaminated water drops that have fallen to the ground; see, e.g., F. B. Krauss, *An Interpretation of the Omens, Portents, and Prodigies Recorded by Livy, Tacitus, and Suetonius* (Philadelphia: University of Pennsylvania Press, 1930), pp. 58–60. But, for one thing, the great frequency of reported "blood rains" argues against this particular interpretation. For another thing, the ancient scientific writers themselves have used the terms "red" and "bloody" in describing what we now know on other grounds to be auroral displays (Aristotle 342a35; Seneca I 14.2; Pliny II 97). Finally, the typical report that "blood rain" was seen in such and such a precinct can be read to mean simply that the viewer was stationed in that particular precinct. Except for the few cases where physical drops are specifically mentioned, I shall maintain an auroral interpretation of "blood rain."

[30] "Milk rain" is recorded only in Livy and his excerptors, and only for the period c. 265 to 92 B.C. Krauss, *An Interpretation,* pp. 65–66, interprets it as fallen raindrops, as he does "blood rain."

It should be emphasized that the ancient authors did not attribute to these categories a single underlying physical cause. This is a modern interpretation, based on a critical selection of sky phenomena that have been abstracted from a much larger number which the ancients described. In the previous auroral catalogues the last six categories have been ignored either partially or entirely.

It is impossible to be certain that every reported event belonging to each of these categories is an aurora. Sufficient detail in the ancient descriptions is nearly always lacking, and some of the events are probably due to other phenomena, such as noctilucent clouds, atmospheric dust, distant lightning, airglow, zodiacal light, meteor showers, and comets (in the modern sense). Of our three main ancient sources, Livy and his excerptor Obsequens only once report a "comet" and only once a "beam" (probably the terms were never used in the official Roman records and histories until Greek scientific knowledge became commonplace in Rome in the first century B.C.).[31] Thus, these two authors as well as our third main source, Cassius Dio, seem to use the word "torch" for all kinds of torchlike displays. Unless specific auroral properties are described, I have had to reject most of the reported "comets" and "torches."

The reports that are here accepted as being probably auroral are listed in Table 1.[32] A question mark placed after an assigned category indicates that the report as a whole, for one reason or another, cannot be regarded as auroral on its own merits. The collection of aurorae is quite homogeneous geographically: all the reported events occurred in Greece, Italy, or southern Gaul, with the exception of three questionable events, one in Egypt (30 B.C.), one in Judea (A.D. 30?), and one in Carthage (A.D. 212?).

The assigned dates depend in large part on the chronologies provided by the ancient authors reporting the events; for early Greece, either the annual Athenian archonship or the Olympiad and year number are usually reported, while for the Roman world the annual consulship, the emperorship and year number, or the year number since the founding of Rome is typically reported. Modern scholarship has been able to establish the necessary links between the ancient and modern systems of reckoning the years (by the help of ancient synchronisms and datable eclipses, for example). Since both the old Athenian year and the Roman year before 153 B.C. did not begin on January 1, and since there was a careless intercalation of months to fill the years before 45 B.C. as well as a poor tradition of the consular lists prior to circa 300 B.C. and even an occasional disagreement among the ancient authorities as to the date of an event, any modern attempt at exact dating is doomed to failure. Chronological accuracy is, in most cases, limited simply to the year of the event, the possible error of the date being $\pm 1$ year, especially for dates preceding the Julian calendar reform of 45 B.C.; dates in Table 1 that are more uncertain than this bear question marks. Of course, in any year more than one aurora may have been reported, although the general rarity of the reports makes this unlikely. Moreover, different

[31] The comet is Caesar's of 44 B.C. (Obsequens 68) and the "beam" occurred in 63 B.C. (Obsequens 61). A documented catalogue of "comets" and "torches" in classical literature has been assembled by W. Gundel, *s.v. Kometen,* in Pauly-Wissowa-Kroll, *Real-Encyclopädie der Classischen Altertumswissenschaft* (Stuttgart: Metzler, 1921), Vol. XI, Pt. 1, cols. 1143–1193.

[32] Lycosthenes lists a number of prodigies for the year 128 B.C. that I cannot locate in the ancient literature. He seems to imply that he drew these reports from Obsequens; but Scheffer thinks not, because they are not found in the Aldine edition of Obsequens. I have not included Far Eastern aurorae in Table 1; but some examples have been listed by S. Kanda, "Ancient Records of Sunspots and Auroras in the Far East and the Variation of the Period of Solar Activity," *Proceedings of the Imperial Academy of Japan,* 1933, *9*: 293–296, and by D. J. Schove, "Sunspots, Aurorae, and Blood Rain: The Spectrum of Time," *Isis,* 1951, *42*: 133–138.

**Table 1. Documented catalogue of ancient auroral reports[a]**

| Year | Category[b] | References |
|---|---|---|
| B.C. 480 | ? | Pliny II 90 (K?); Lydus, *De mensibus* IV 73 (K?) |
| 468/467 | SF, B | Daimachus in Plutarch, *Lysander* XII 4 (SF); Charmander in Seneca VII 5.3 (B); Pliny II 149 (K?); Aristotle 344b34 (K?); Alexander of Aphrodisias, *ad loc.* (K?); Philoponus, *ad loc.* (K?); Olympiodorus, *ad loc.* (K?) |
| 464/463? | SF | Livy III 5.14 (SF); Orosius II 12.2 (SF) |
| 461? | SF | Livy III 10.6 (SF) |
| 459? | SF | Dionysius of Halicarnassus X 2.3 (SF) |
| 395/394? | B | Pliny II 96 (B) |
| 373/371 | B, T | Diodorus Siculus XV 50.2–3 (B, T); Callisthenes in Seneca VII 5.3 (B); *Parian Marble,* ep. 71 (T?); Pausanius VII 24.8 (T?); Aristotle 343b1, b18, 344b34 (K?); Alexander of Aphrodisias, *ad loc.* (K?); Philoponus, *ad loc.* (K?); Olympiodorus, *ad loc.* (K?); Aristotle in Seneca VII 5.4 (K?); Ephorus in Seneca VII 16.2–3 (K?) |
| 350/349 | X, BR, SF | Pliny II 97 (X, BR, SF); Lydus, *De ostentis* 10b (X, SF) |
| 345/344 | X, SF, T | Plutarch, *Timoleon* VIII 5–7 (X, SF, T); Diodorus Siculus XVI 66.3 (T); Pliny II 90 (K?) |
| 265? | ? | Orosius IV 5.1 (MR?); Paulus Diaconus II 16 (MR?) |
| 223 | SF, NS | Orosius IV 13.12 (SF, NS); Paulus Diaconus III 2 (SF,NS); Zonaras VIII 20 (SF, NS) |
| 217 | X, SF | Livy XXII 1.11–12 (X, SF); Orosius IV 15.1 (X); Paulus Diaconus III 9 (X); Plutarch, *Fabius Maximus* II 3 (X); Silius Italicus VIII 630–651 (X?, SF?, BR?, K?) |
| 214 | BR | Livy XXIV 10.7 (BR) |
| 209 | MR | Livy XXVII 11.5 (MR) |
| 206 | NS | Livy XXVIII 11.3 (NS) |
| 204 | NS | Livy XXIX 14.3 (NS) |
| 200 | SF | Livy XXXI 12.5 (SF) |
| 198 | SF | Livy XXXII 9.2 (SF) |
| 197 | NS | Livy XXXII 29.2 (NS) |
| 183 | BR | Livy XXXIX 46.5, 56.6 (BR); Obsequens IV (BR) |
| 181 | BR | Livy XL 19.2 (BR); Obsequens VI (BR) |
| 172 | BR | Livy XLII 20.5 (BR) |
| 169 | SF | Livy XLIII 13.3 (SF), 13.5 (BR?) |
| 168 | ? | Seneca I 1.2 (K?) |
| 166 | NS, BR | Obsequens XII (NS, BR) |
| 163 | SF, NS, MR | Obsequens XIV (SF, NS, MR) |
| 162 | SF | Obsequens XV (SF) |
| 147 | SF | Obsequens XX (SF) |
| 134 | NS, BR | Obsequens XXVII (NS, BR) |
| 130 | MR | Obsequens XXVIII (MR) |
| 128 | BR | Obsequens (?) in Lycosthenes (BR, T?) |
| 125 | MR | Obsequens XXX (MR) |
| 124 | MR | Obsequens XXXI (MR) |
| 118 | MR | Obsequens XXXV (MR) |
| 117 | MR | Obsequens XXXVI (MR) |
| 114 | BR, MR | Pliny II 147 (BR,MR); Lydus, *De ostentis* 6 (BR, MR) |

| Year | Category[b] | References |
| --- | --- | --- |
| 113 | SF, NS | Obsequens XXXVIII (SF); Pliny II 100 (NS) |
| 111 | MR | Obsequens XXXIX (MR) |
| 108 | MR | Obsequens XL (MR) |
| 106 | BR, MR | Obsequens XLI (BR, MR) |
| 104 | BR, MR | Obsequens XLIII (BR, MR, SF?); Plutarch, *Marius* XVII 4 (SF?); Pliny II 148 (SF?) |
| 102 | NS, BR | Obsequens XLIV (NS, BR) |
| 95 | MR | Obsequens L (MR) |
| 94 | SF | Obsequens LI (SF, T?) |
| 93 | X, SF | Obsequens LII (X, SF, BR?) |
| 92 | MR | Obsequens LIII (MR, BR?) |
| 91 | X, BR | Sisenna in Cicero, *De divinatione* I 99 (X, BR) |
| 63 | SF, B, K | Cicero, *In Catilinam* III 8 (SF); Cicero in Cicero, *De divinatione* I 18 (K, T?); Obsequens LXI (B); Dio XXXVII 25.2 (T?) |
| 49 | SF, BR | Lucan I 527–529 (SF, K?); Appian II 36 (BR); Dio XLI 14.3 (SF?); Pliny II 92 (K?) |
| 48 | B, P | Lucan VII 155–156 (B, P); Plutarch, *Caesar* XLIII 3 (T?); Appian II 68 (T?); Dio XLI 61.2 (T?); Zonaras X 9 (T?) |
| 44 | ? | Ovid XV 788 (BR?) |
| 42 | SF, NS | Manilius I 907 (SF); Obsequens LXX (NS); Dio XLVII 40.2 (NS); Zonaras X 19 (NS); Vergil I 488 (K?) |
| 32 | T | Dio L 8.2 (T) |
| 30 | ? | Dio LI 17.4–5 (BR?, K?) |
| B.C. 17 | T | Obsequens LXXI (T); Dio LIV 19.7 (T) |
| A.D. 9 | SF, P, K | Manilius I 901–902 (SF); Dio LVI 24.3–4 (SF, P, K) |
| 14 | SF, BR, K | Dio-Xiphilinus LVI 29.3 (SF, BR, K); Zonaras X 38 (SF, BR, K); Seneca VII 17.2 (K?) |
| 30? | ? | Pseudo-Pilate (NS?) |
| 39? | BR | *Oracula Sibyllina* X 56–57 (BR) |
| 50 | SF | Dio-Xiphilinus LX 33.2 (SF); Zonaras XI 10 (SF) |
| 54 | BR | Dio-Xiphilinus LX 35.1 (BR) |
| 76 | K | Titus in Pliny II 89 (K) |
| 185? | ? | Lampridius, *Commodus* XVI 2 (SF?); Herodian I 14.1 (K?) |
| 196 | SF | Dio-Xiphilinus LXXV 4.6 (SF) |
| 212? | ? | Tertullian, *Ad Scapulam* III (SF?) |
| 300? | ? | *Oracula Sibyllina* XII 89–90 (BR?) |
| 333 | SF | Aurelius Victor XLI (SF) |

[a]**Sources:** Alexander of Aphrodisias, *In Aristotelis Meteorologica*; Appian, *Civil Wars*; Aristotle, *Meteorologica*; Aurelius Victor, *Caesars*; Cicero, *De divinatione, In Catilinam*; Dio-Xiphilinus, *Roman History;* Diodorus Siculus, *Library of History*; Dionysius of Halicarnassus, *Roman Antiquities*; Herodian, *Ab excessu divi Marci*; Lampridius, *Vita Commodi (Historia Augusta)*; Livy, *Ab urbe condita*; Lucan, *Pharsalia*; Lydus, *De mensibus, De ostentis;* Manilius, *Astronomicon*; Obsequens, *Prodigiorum liber*; Olympiodorus, *In Aristotelis Meteorologica*; Anonymous, *Oracula Sibyllina*; Orosius, *Adversum paganos*; Ovid, *Metamorphoses*; Anonymous, *Parian Marble*; Paulus Diaconus, *Roman History*; Pausanias, *Description of Greece*; Philoponus, *In Aristotelis Meteorologica*; Pliny the Elder, *Naturalis historia*; Plutarch, *Parallel Lives*; pseudo-Pilate, *Report to Caesar*; Seneca, *Naturales quaestiones*; Silius Italicus, *Punica;* Tertullian, *Ad Scapulum;* Vergil, *Georgics;* Zonaras, *Annals.*

[b]**Categories:** B = beam; BR = blood rain; K = aurora-like comet; MR = milk rain; NS = night sun; P = pillar; SF = sky fire; T = aurora-like torch; X = chasm.

reports for the same year may, in some instances, refer to entirely different phenomena. On the other hand, not all the reports are of independent value, because later authors have necessarily borrowed from their predecessors. Finally, it is typical that more reports tended to be generated, or later remembered, during times of stress and of other notable events.

A few comments about the three largest gaps in the auroral record seem to be called for, since some authors, such as Schove, have identified these gaps with aurorally quiet periods.[33] The first gap occurs in the Roman record between 459 and 223 B.C. Our main reference for this period, Livy's history, suffers both from a dearth of reliable early records in his time (due in part to the burning of Rome by the Gauls c. 390 and in part to the irregularity of the Roman pontifical annals before c. 300) and also from the loss in postclassical times of those intermediate books of his history that cover the years 292 to 220. However, aurorae did occur during at least the earlier half of this long period, as is demonstrated by the four examples of Greek aurorae preserved by later Roman writers. Yet not a single aurora from the fourth and fifth centuries is reported in the great contemporary Greek histories that are still extant; this silence is undoubtedly due to those historians' very sober attitudes toward portents of all kinds. The second gap in the auroral record falls between 91 and 49 B.C. (with the exception of the year 63 B.C.). As may be judged by Obsequens' extracts from Livy's history, the unprecedented civil wars of that period bred a growing public disrespect for portents[34] and apparently interrupted the transmission to Rome of reports of many aurorae that must nonetheless have been noted. Finally, the series of gaps after A.D. 76 is at least partly due to the well-known paucity of historical records for the late Roman Empire. In sum, I can find no good historical evidence either for or against the supposition that the gaps in the record are associated with aurorally quiet periods.

## THE ANCIENT AURORAL CYCLE

Because of the fragmentary nature of the auroral record in Table 1, standard methods of analyzing this record for possible periodicities fail. Thus, Nicolini, Schove, and Link simply assumed in their work an eleven-year cycle of variability in analogy with the modern auroral and sunspot cycles.[35] In part, their failure stemmed from not having had an adequate catalogue. Schove listed, for the period before A.D. 300, only thirteen auroral years that he regarded as suitable for mathematical analysis; of these, a mere six lay in the well-documented interval 223–91 B.C. But I find thirty-six useful auroral years in the latter time interval.

With the help of an appropriate method of time series analysis, I have recently searched for possible cycles in the ancient auroral data. Since the results of this analysis have already been presented,[36] it suffices here merely to summarize the main points. First, there were sufficient data in the interval 223–91 B.C. to analyze separ-

[33] D. J. Schove, "The Sunspot Cycle, 649 B.C. to A.D. 2000," *Journal of Geophysical Research*, 1955, *60*:127–146.

[34] For other causes see Krauss, *An Interpretation*.

[35] Nicolini, "Sull' andamento secolare dell' attività solare"; Schove, "The Sunspot Cycle"; F. Link, "Manifestations de l'activité solaire dans le passé historique," *Planetary and Space Science*, 1964, *12*: 333–348. Pliny (II 97) originally suggested that "chasms," "beams," and the like were periodic phenomena, but in this opinion he was simply following Pythagorean and Chaldean cometary tradition.

[36] R. Stothers, "Solar Activity Cycle during Classical Antiquity," *Astronomy and Astrophysics* (in press). This research has depended heavily on the classics collections of the Columbia University Libraries and the New York Public Library.

ately the categories of "sky fire," "night suns," "blood rain," and "milk rain." These categories showed virtually the same period of cyclical variation, suggesting that they were merely different manifestations of the same phenomenon. The mean period was 11.5 years, with a scatter of less likely periods ranging from 8 to 13 years. A longer period of 80 to 100 years was also present in the data. Second, it was found that the average frequency of visible aurorae near Rome was approximately three per decade. Since these results resemble so closely the characteristics of modern aurorae, it would seem that the second century B.C. was very similar to our own century as far as aurorae are concerned.

## CONCLUSION

Whatever merit may exist, for us today, in the numerous examples of celestial prodigies recorded during the later centuries of antiquity, it is clear that auroral science in the ancient West made no significant progress in either classification or theory after the age of Aristotle. Insuperable technological barriers stood in the way at the time, as did the unavoidable fact that visible aurorae are rare and of short duration in the Mediterranean area. Moreover, the apparent unpredictability of aurorae made them less interesting to the ancients.

It has been left to modern science to devise a formal classification scheme for these neglected legacies from antiquity. The system proposed in this paper is believed to be the simplest and most useful of those that have been suggested, as it is very close to the one used by the ancients themselves in classifying the various observed kinds of unusual celestial phenomena. Underlying any system, of course, is the tacit assumption that ancient and modern aurorae look the same visually.

With the help of a new survey of the classical literature, I have put together an extensive catalogue of reports of what are likely to have been auroral displays. This catalogue certainly has statistical value, even though individual entries may be rather uncertain. It appears possible, from this catalogue, that auroral activity was continuous at some level of visibility throughout recorded antiquity. In fact, during the best-documented period—the second century B.C.—the auroral cycle seems to have been very similar to what it is today.

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ASTRONOMY AND ASTROPHYSICS

# Solar Activity Cycle during Classical Antiquity

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**Summary.** Early accounts of phenomena that may be identified as auroral displays have been abstracted from reports of unusual celestial prodigies in the classical literature. An extensive catalog of ancient aurorae and a new mathematical method of analyzing fragmentary time series of observations have been used to demonstrate, provisionally, that an auroral cycle actually existed in antiquity, at least during the 2nd century BC, and that it had an average length and amplitude comparable with those of the modern auroral cycle. On the reasonable supposition that solar activity has always been the factor responsible for aurorae, it can be concluded that the solar cycle two millennia ago was very similar to what it is today.

**Key words:** aurora borealis — solar cycle — statistical analysis — ancient observations

## I. Introduction

In a now famous monograph on the aurora borealis, de Mairan (1733) first drew modern attention to reports of certain transient sky phenomena found in the works of some of the better known classical authors. One of these authors was Pliny the Elder, who wrote (AD 77):

> There are also stars that suddenly come to birth in the heaven itself; of these there are several kinds.... "beams", in Greek *dokoi*, for example one that appeared when the Spartans were defeated at sea and lost the empire of Greece. There also occurs a yawning of the actual sky, called *chasma*, and also something that looks like blood, and a fire that falls from it to the earth – the most alarming possible cause of terror to mankind.... A light from the sky by night, the phenomenon usually called "night-suns", was seen in the consulship of Gaius Caecilius and Gnaeus Papirius and often on other occasions causing apparent daylight in the night.

These remarkable phenomena de Mairan concluded were displays of the aurora borealis. The simple forms and colors that Pliny and other ancient authors described call to mind the rare modern aurorae that occur at low geomagnetic latitudes. But historical studies of the aurora have left largely unsurveyed the available classical record. It is true that four catalogs of aurorae from this record have been compiled and published (Frobesius, 1739; Fritz, 1873; Schove, 1948; Link, 1962), but because only token recourse to the original literature was made by the modern compilers, who chose to rely on a number of incomplete and heterogeneous 16th and 17th century collections of ancient prodigies, the catalogs abound in unfortunate errors of mistaken contexts, incorrect dates, and numerous omissions. A detailed criticism of these catalogs is given in a paper to appear soon in *Isis*, to which the reader is referred (Stothers, 1979). In their place I have compiled a new, exhaustive catalog directly from the ancient literature itself.

With such a catalog it becomes possible, for the first time, to analyze the data statistically in order to determine whether or not an auroral cycle existed during antiquity, and, if so, what its length and amplitude were. These results then immediately disclose something about the solar activity cycle, if the reasonable assumption is made that solar activity was then, as now, the controlling factor in producing aurorae. A statistical treatment of the ancient data seems to be unavoidable if for no other reason than that a certain number of mistaken identifications of aurorae are bound to have been made by any compiler, no matter how conscientious. Previous authors, such as Schove (1955), Nicolini (1963, 1976), and Link (1964), did not use a statistical approach. They essentially assumed an auroral cycle approximately equal to the 11-year cycle of solar activity that exists today. Eddy (1976), among others, has recently questioned whether this solar cycle actually existed before the 17th century. I hope to show not only that it did, but also that it had virtually the same characteristics during the 2nd century BC as it has today.

## II. The New Catalog

It is clear from Pliny's brief description that ancient aurorae are to be sought among accounts of unusual celestial portents and prodigies. A useful procedure, therefore, is to retain the ancient classifications of sky phenomena for the sake of uniformity, since these classifications seem to have kept their meanings unchanged throughout antiquity. Phenomena that I tentatively class as auroral are the following: "chasms" (X), "sky fire" (SF), "night suns" (NS), "blood rain" (BR), "milk rain" (MR), "beams" (B), "pillars" (P), aurora-like "torches" (T), and aurora-like "comets" (K). Objects in these categories have, of course, some possibility of being confused occasionally with ordinary comets, meteoric fireballs, zodiacal light, and so on. Therefore, the ultimate test of the correctness of the classifications must be based on an objective statistical analysis.

The previous auroral catalogs lacked a practical classification system. In fact, the last six of the nine categories listed

above were largely ignored in the earlier work. Schove (1955), in his second paper, may have included some of these six, but he has published neither the classifications nor the sources of his reports – only the dates. In any case, there are only six auroral years between 223 and 91 BC that he regards as suitable for mathematical analysis. In this interval I find 36 suitable years.

An abridged version of the new catalog is given in Table 1 for convenience. Details that are not of direct scientific interest, such as source references, questionable reports, and dating methods, are to be found in my *Isis* article. Probably the individual dates listed are accurate to within $\pm 1$ yr. Continuity of the auroral record is poor in some centuries, but this can be explained adequately within the context of the fragmentary nature of the historical records. Climatic factors are almost certainly not responsible for the large gaps, as the ancient historians do not refer to whole decades of overcast skies; in fact, a stretch of even months of uninterrupted dimness of the sun was enough to cause surprised comment in ancient times. A high degree of geographical homogeneity characterizes the auroral catalog, since all the listed events refer to areas along the northern rim of the Mediterranean basin. In the almost continuously documented period 223–91 BC, the reporting area is narrowed down to central Italy and the source material is also very uniform, being taken, directly or indirectly, from Livy's great annalistic history of Rome (written between 27 BC and AD 17). In Livy's history the portents noted each year in public Roman territory are carefully enumerated, for the reason, he says (*Ab urbe condita* 43.13), that in those early days of Rome they were regarded as serious religious matters related to the welfare of the state. Their veracity was, it would seem, diligently checked into by the authorities because the rites necessary to expiate them were costly and time-consuming. I have no reason to doubt the trustworthiness of Livy's sources for these portents.

It is a happy accident of history that ancient civilization in Europe developed around low geomagnetic latitudes. For, if modern aurorae are admitted as a provisional guide to ancient ones, a small (but not negligible) number of aurorae are expected to have been easily visible in any decade down through the centuries at the low latitudes of the Mediterranean countries (Fritz 1881). In northern Europe, however, every year would have been an auroral year. In that case, unless the number of aurorae per year had been recorded (and it is known that such statistics were not kept during medieval times in the North), no reliable information about the ancient auroral cycle could have been derived today. On the other hand, at more southerly geomagnetic latitudes, only an extremely rare aurora every few decades would have been easily noticeable. It is, therefore, of critical importance that Table 1 is found to contain just a small number of auroral reports each decade during the best documented period 223–91 BC.

## III. A Mathematical Method of Time Series Analysis

The data in Table 1 comprise a discrete time series of observations which could be seriously affected both by incompleteness and by a number of mistaken identifications. Periodicities (or mean cycle times) in poor, noisy records of this kind are usually looked for in one of two ways. The first way is to accumulate the observations into "bins", so that a power spectrum, or periodogram, analysis can be performed. In the present instance, the bin size necessary to obtain a statistically significant sample would be very large, probably larger than the anticipated period. The second way of locating the dominant period is to fit the observations to an equation of the form

$$t_{\max} = t_0 + nP, \tag{1}$$

where $t_{\max}$ is the time of the $n$th maximum in the observations, and $P$ and $t_0$ are the period and epoch to be determined. In practice, it is necessary first to bin the observations so that the times of maximum can be determined, and then to assign an

**Table 1.** Catalog of ancient aurorae mentioned in classical literature

| Year | Category | Year | Category | Year | Category |
|---|---|---|---|---|---|
| | | BC 166 | NS, BR | BC 95 | MR |
| BC 467 | SF, B | 163 | SF, NS, MR | 94 | SF |
| 373 | B, T | 162 | SF | 93 | X, SF |
| 349 | X, BR, SF | 147 | SF | 92 | MR |
| 344 | X, SF, T | 134 | NS, BR | 91 | X, BR |
| 223 | SF, NS | 130 | MR | 63 | SF, B, K |
| 217 | X, SF | 128 | BR | 49 | SF, BR |
| 214 | BR | 125 | MR | 48 | B, P |
| 209 | MR | 124 | MR | 42 | SF, NS |
| 206 | NS | 118 | MR | 32 | T |
| 204 | NS | 117 | MR | BC 17 | T |
| 200 | SF | 114 | BR, MR | AD 9 | SF, P, K |
| 198 | SF | 113 | SF, NS | 14 | SF, BR, K |
| 197 | NS | 111 | MR | 50 | SF |
| 183 | BR | 108 | MR | 54 | BR |
| 181 | BR | 106 | BR, MR | 76 | K |
| 172 | BR | 104 | BR, MR | 196 | SF |
| 169 | SF | 102 | NS, BR | 333 | SF |

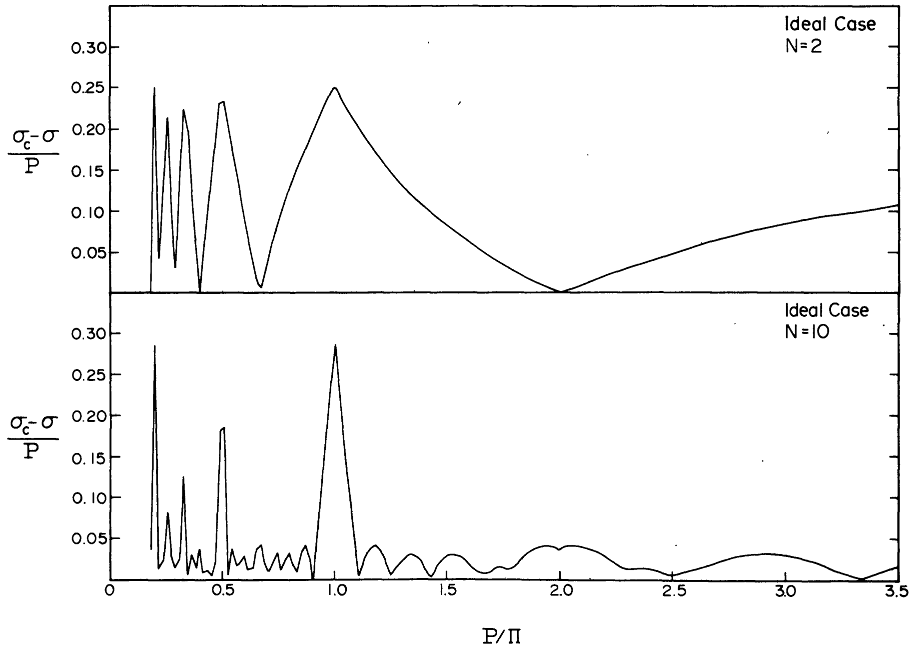


**Fig. 1.** Spectra of the residuals index $(\sigma_c - \sigma)/P$ for two ideal cases, where $\Pi$ is the true period

integer $n$ to each estimated $t_{\max}$ value on the basis of some assumed period $P$ and assumed epoch $t_0$. Finally, a formal least-squares fit to Eq. (1) is made to find the definitive values of $P$ and $t_0$. In suitable situations, graphical or tabular variants of this method can be devised. These procedures, however, do not generally determine the true period; they merely find the best-fitting period that lies in the immediate neighborhood of the assumed period, or, at most, they show that the assumed period is not grossly incompatible with the observations (Nicolini, 1976; Schove, 1955; Link, 1964).

In order to remove these inadequacies, I have used the following method of analysis, which should be generally applicable to any time series that is composed of sampled time intervals (not necessarily equally spaced) during which the only known information is whether an observation was or was not generated. First, a suitable array of trial periods is set up. For each trial period, $P$, a selection of trial epochs, running from $t_0$ to $t_0 + P$, is made. Then Eq. (1) is used to generate a continuous sequence of predicted times of maximum for each combination of trial period and trial epoch. A particular observation is assigned, within a given generated sequence, to the nearest predicted time of maximum. The difference between the observed time and the predicted time of maximum will be denoted $d_i (i = 1, 2, \ldots, N$, for $N$ observations). Then, for each sequence, the following rms residual is computed.

$$\sigma = \left(\sum_{i=1}^{N} d_i^2/N\right)^{1/2}. \tag{2}$$

A straightforward criterion of best fit is the minimum value of $\sigma/P$ that is found when all the sequences have been analyzed in the foregoing fashion.

A simple mathematical example will suffice to demonstrate the method and to provide a useful paradigm by which more sophisticated physical results can be interpreted. Consider a sequence of $N$ numbers with a constant difference $\Pi$ between successive numbers. In this simple example, the true period is known in advance to be $\Pi$, but an unprejudiced period analysis will be performed for illustration. At each trial period the smallest value of $\sigma/P$ is selected from all the values that have been generated with various trial epochs. Since it is more conventional to have an *increasing* index to measure probability of a good fit, I shall henceforth adopt the variable $(\sigma_c - \sigma)/P$, where the constant term is given by

$$\sigma_c/P = [(N^2 - 1)/12\, N^2]^{1/2}. \tag{3}$$

This constant can be shown to represent the continuous part of the spectrum of residuals $\sigma/P$ that lie between $P = 0$ and $P = N\Pi$. (For $P > N\Pi$, $\sigma/P$ is proportional to $P^{-1}$.) Over the complete range of $N$, the continuum value varies only slightly: $0.250 \leqq \sigma_c/P \leqq 0.289$ for $2 \leqq N \leqq \infty$.

A period analysis for the present example is shown in Fig. 1. Here the trial periods run from 0.20 $\Pi$ to 3.50 $\Pi$, in steps of 0.02 $\Pi$. The analysis has been performed for $N = 2$ and 10. In general, the spectrum of $(\sigma_c - \sigma)/P$ values takes the form of a zero-valued continuum broken by a series of high and low maxima. Wherever $P$ equals the true period $\Pi$ or any harmonic thereof ($\Pi/2$, $\Pi/3$, etc.) the spectrum has a high, sharp maximum. (On account of the limited spectral resolution in Fig. 1, not all the harmonics can be seen). Integer multiples of the true period (2$\Pi$, 3$\Pi$, etc.) are associated with wider, lower maxima. In general, as $N$ is increased, all the maxima become narrower, and, because the noisiness of the spectrum is also reduced, they are more sharply defined.

From this idealized case certain general inferences can be drawn. First, since the continuous part of the spectrum of residuals $\sigma/P$ has proven to be nearly independent of $N$, it is expected to be relatively independent of the pattern of observations in more complicated situations. Therefore $(\sigma_c - \sigma)/P$ remains a good index. Second, if there are any gaps in the series of observations (consider Fig. 1 with a harmonic of $\Pi$ as the true period), these gaps are expected to be far less instrumental in lowering the spectral peak at the true period than are the accidental intrusions of spurious observations (consider Fig. 1 with an integer multiple of $\Pi$ as the true period). Third, the

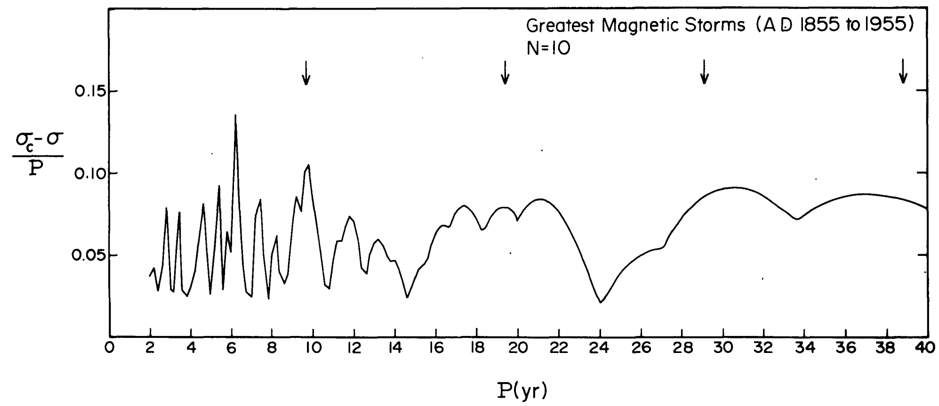


**Fig. 2.** Spectrum of the residuals index $(\sigma_c - \sigma)/P$ for the greatest magnetic storms on record between AD 1855 and 1955. Arrows mark the most probable period and its integer multiples

presence of gaps in the observations are expected to lead to a greater prominence of the spectral peaks that occur at integer multiples of the true period and hence to "alias" periods.

More specific inferences for the case where $N$ is close to 10 and where gaps in the observations may occur are of interest in the applications below. According to the idealized case just discussed, four or five subsidiary maxima occur between $P = \Pi$ and $P = 2\Pi$; and between $P = 2\Pi$ and $P = 3\Pi$ one or two occur. Thus, counts of subsidiary maxima may also help in identifying the true period. That this pattern does depend on the existence of a true period, and is not simply an artefact produced by the number of observations may be seen by considering the very different pattern that exists in the vicinity of a trial period which is $N$ times the true period (compare the vicinity of $P/\Pi = 1$ with the vicinity of $P/\Pi = 2$ for $N = 2$ in Fig. 1).

## IV. The Modern Auroral Cycle

Since the ancient auroral observations will be analyzed in the fashion just indicated, it is instructive to have also a comparable analysis of modern auroral data. A sample closely analogous to the ancient sample insofar as the geomagnetic latitude and total number of events are concerned is provided by the greatest "magnetic storms" and aurorae on record in modern times. During the period 1855–1955, they occurred in the following years: 1859, 1872, 1882, 1903, 1909, 1921, 1938, 1940, 1941, and 1946 (Chapman, 1957). A straightforward average interval between these events is 9.7 yr. But this type of average is very misleading because the observations are clustered in some cases (e.g., 1938, 1940, 1941) and show apparent gaps in other cases (e.g., between 1882 and 1903). Instead, a high-resolution spectral analysis of these observations has been performed in the manner indicated above, and is shown in Fig. 2. Obviously, very short periods such as 1 yr can exactly fit the data (since an undetermined number of gaps may be present), but common sense suggests examining trial periods in the vicinity of the average data interval, or less restrictively, trial periods longer than, say, 2 or 3 yr. Clearly, if no hint of a period exists in a preliminary scrutiny of the data, any formal period analysis is pointless. In the present case, the assumption of a very short period is manifestly unrealistic because this would imply that the majority of auroral maxima have been missed (either because of a lack of attention on the part of potential observers or because of bad weather or an unusual weakness of the missed maxima). On the other hand, an examination of the average data interval does suggest that some sort of periodicity is present in the modern auroral data.

Despite the paucity of observations and their spotty distribution in time, a best-fitting period of 9.7 yr (accidentally the same as the straightforward average interval) can be derived. Notice in Fig. 2 that both the relatively large size of the main maxima (corresponding to the period and its integer multiples) and the number of subsidiary maxima lying between successive integer multiples of the period are in accord with the spectrum expected for a periodic phenomenon that is affected by the presence of some gaps as well as some clustering or noise. Additionally, the large peak near 6 yr appears to be the first harmonic of another period of about 12 yr. The simple conclusion to be drawn is that the "true" period lies somewhere in the range 9–12 yr.

Over the same time interval, sunspot maxima (with which great magnetic storms and aurorae are known to be correlated) occurred in the years 1860, 1870, 1883, 1893, 1905, 1917, 1928, 1937, and 1947 (Abetti, 1957). These maxima are best fitted by a period of 11.1 yr (the straightforward average interval is 10.9 yr). Even with such a very small number of observations, the results for the modern auroral and sunspot cycles are in essential agreement with previously known results based on a much larger number of observations, and demonstrate the usefulness of the new method of analysis.

## V. The Ancient Auroral Cycle

From the catalog of ancient aurorae in Table 1, sufficient data are at hand to consider separately the categories SF, NS, BR, and MR, in the well-documented time interval 223–91 BC. An analysis of each case is shown in Fig. 3. Despite the appreciable noise, the individual spectra yield the following periods:

SF, 8.7 yr;
NS, 10.2 yr;
BR, 13.3 (?) yr;
MR, 11.6 (?) yr.

Other periods in the range 8–13 yr are also possible from these data. The resemblance of both the overall spectra and the derived periods to the results for modern aurorae tend to confirm the identification of "sky fire" and "night suns" as being in most cases auroral displays. However, the results for

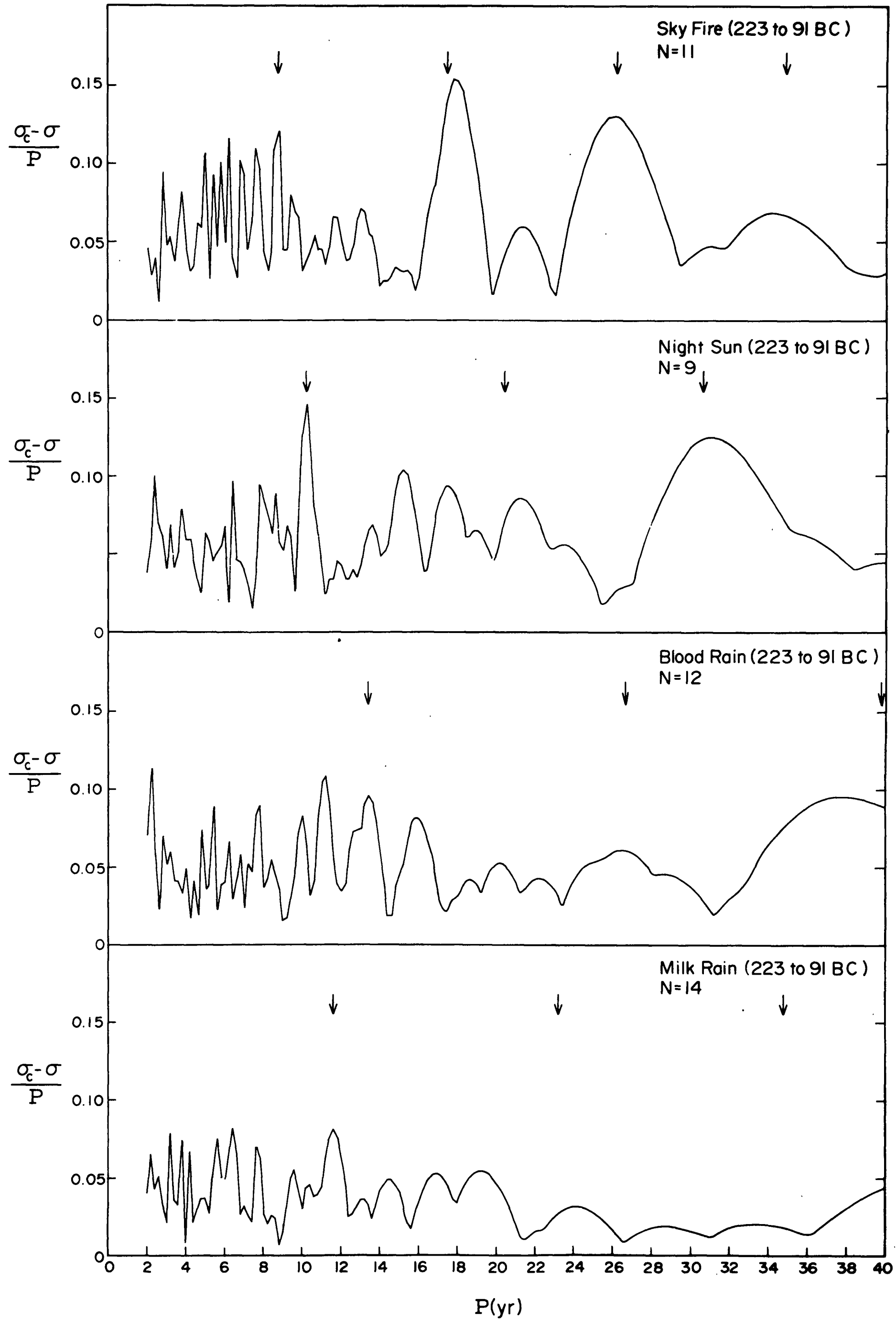


**Fig. 3.** Spectra of the residuals index $(\sigma_c - \sigma)/P$ for four types of ancient sky phenomena that may be auroral displays (223–91 BC). Arrows mark the most probable period and its integer multiples

"blood rain" and "milk rain" are rather marginal, and show what a nearly random spectral record might look like. If all four categories are analyzed together, the resulting period is 11.5 yr.

An additional analysis can be made by using all the data in Table 1, from 467 BC to AD 333. In analyzing these data, it must be remembered that there is no year "zero" in the historical system of dating, so that for computational purposes the BC dates must be decreased by 1 yr and then made negative in order to conform to the astronomical system. A period of 15.0 yr is found to provide a best fit to all the data. The next most probable periods are 8.7 and 11.1 yr. But since the large gaps in the record of eight centuries of observation have probably tended to distort the derived period, the previous value of 11.5 yr should be definitely preferred as the best period that can be extracted.

Since it is doubtlessly true that aurorae were caused in the past, as now, by the interaction of the solar wind with the earth's upper atmosphere, the ancient auroral cycle can be directly equated with the ancient solar cycle, apart from a possible difference of phase. In respect to the average cycle length, the agreement between ancient and modern solar cycles is good and implies a certain regularity of the sun's rhythm over an interval of over 2000 yr. In respect to the amplitude of the cycle, solar

activity in the 2nd century BC was also probably very nearly the same as it is today, since the incidence of visible aurorae near Rome is found to be, in both periods, about 3 per decade. However, our knowledge that a prolonged minimum in solar and auroral activity occurred between AD 1645 and 1715 serves as a warning that the 2nd century BC, like the present century, may not be representative of all eras.

It is curious that ancient reports of "chasms" recur cyclically at much longer intervals of about 125 yr. The recorded dates of observation are 349, 344, 217, 93 and 91 BC. The great event of 467 BC also fits this sequence. Whether such a long period has any physical significance cannot be determined because the historical records are so incomplete. But during the well-documented time interval 223–91 BC a secondary cycle of 80 to 100 yr seems to fit the data well, as is indicated chiefly by the long auroral minimum from 162 to 134 BC. It is perhaps not merely coincidental that, in more recent centuries, an auroral and sunspot cycle of some 80 yr has been in steady operation (Schove, 1955; Link, 1964; Abetti, 1957).

A few words are necessary concerning the nature of direct observations of solar variability during classical antiquity. To begin with, there exist a number of reports in the classical literature of unusual changes in the sun's size, brightness, and color. These changes have not attracted much modern attention, perhaps because they are so obviously explained by purely optical effects produced in the earth's atmosphere and by unrecognized solar eclipses. However, minor solar changes have been the subject of frequent commentary over the years. These changes fall into three categories. First are the dark "spots" often mentioned by classical writers on weather lore, beginning at least with Theophrastus (*De signis tempestatum* 1.11, 2.27, 4.50) and Aratus (*Phaenomena* 819–839). However, these "spots" are almost certainly not what we mean today by "sunspots", which are rarely and with difficulty perceptible to the naked eye; rather, since they are stated to be readily visible at sunrise, to occur sometimes on the moon, and to prognosticate a rainy day, they would seem to be merely small terrestrial clouds seen projected on the sun's disk. A more interesting inference of a sunspot observation has been made by Bicknell (1968), who has noted that Anaxagoras (5th century BC) once predicted, at a time of probable auroral maximum, that a large stone would fall from the sun. A second category of solar change is the occurrence of a bright or dark "halo" around the uneclipsed sun. This atmospheric phenomenon is frequently reported in classical literature, and was explained, correctly, as early as the 4th century BC, by Aristotle (*Meteorologica* 371b–378a). Third, there are phenomena associated with the eclipsed sun. At the time of solar maximum, the corona is greatly enhanced and could be easily visible during a total solar eclipse. However, if the eclipse is annular rather than total, the sun's rim itself would appear as a fictitious "corona". In the absence of further details, an unavoidable ambiguity must attend the ancient reports of "the visible light about the rim of the eclipsed sun" (Cleomedes, *De motu circulari corporum caelestium* 2.105; Plutarch, *De facie quae in orbe lunae apparet* 932B) and "the comet that once was seen near the sun when the latter was eclipsed" (Posidonius in Seneca, *Naturales quaestiones* 7.20.4; Ptolemy, *Tetrabiblos* 2.9; Arrianus Meteorologicus in Stobaeus, *Eclogae* 1.28.2). In summary, there seems to be reasonable doubt that either sunspots or the solar corona was ever observed in the ancient West, although sunspots were more certainly reported in China during the same period (Kanda, 1933; Schove, 1951).

## VI. Conclusions

The ancient prodigies of "sky fire" and "night suns" (and, more uncertainly, of "blood rain" and "milk rain") appear to be phenomena closely allied to each other, since they show virtually the same cyclical variation during the well-documented time interval 223–91 BC. The period that best fits this cyclical variation is 11.5 years, with a scattering of other possible periods ranging from 8 to 13 years. It is remarkable how closely these periods resemble the ones found for the modern auroral cycle. Thus, they tend to confirm an auroral identification of the four classes of phenomena listed above, although the identification of the very rare "chasms" and "beams" necessarily rests on descriptive evidence alone. Unfortunately, it is not possible to construct a timetable for ancient aurorae that is trustworthy enough to identify individual cases as genuine or false. Great aurorae follow the unpredictably variable solar cycle and, moreover, can appear at almost any phase during this cycle (at least they have in modern times). But this lack of precise predictability does not, of course, vitiate the mean period derived from the accumulation of many cycles. Auroral statistics also suggest that the frequency of aurorae visible near Rome in the 2nd century BC was comparable with the frequency existing now. From these bits of evidence it may be fair to conclude that solar activity two millenia ago was not markedly different from what it is today.

If the available statistics of the ancient auroral record seem rather paltry to the reader, and the results correspondingly uncertain, he should reflect that no significant increase in the literary evidence is likely to be forthcoming (unless the ancient Far Eastern annals prove to be more fruitful than they have been in investigations to date – e.g., Kanda, 1933; Schove, 1951). Therefore, I have considered it worthwhile to present the evidence as it stands today. Perhaps in the future, entirely different methods will be able to provide data concerning the solar cycle in the ancient historical past.

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# Reports

## Historic Volcanism, European Dry Fogs, and Greenland Acid Precipitation, 1500 B.C. to A.D. 1500

Abstract. *Historic dry fogs in Europe, acid precipitation in Greenland, and major explosive volcanic eruptions correlate well with each other between 1500 B.C. and A.D. 1500. European (Mediterranean and Icelandic) volcanic eruptions appear to be the source of at least five of the nine largest acidity signals found in Greenland ice for this period. Between 152 B.C. and A.D. 43, eruptions of sulfur-rich Mount Etna probably supplied about 15 percent of the smaller acidity signals.*

A continuous record of past explosive volcanism in the world can be determined at a single site by two very different methods. One method is based on measuring acidity signals in annual layers of polar ice (*1*). Large peaks of acidity represent deposition of acid aerosols generated by explosive eruptions which, if distant, must have affected the global atmosphere but, if nearby, might have had only regional atmospheric impact. Tropospheric winds will usually carry the low-lying part of the volcanic cloud only a short distance before the particles fall out, but stratospheric winds will inevitably extend the upper part longitudinally around the globe and carry the whole mass poleward as it slowly settles out. Therefore, in order to use the ice-core acidity record as a quantitative measure of global volcanic aerosols, the location of the eruption source must be determined.

Modern eruptions that have generated enough aerosols to produce major acidity peaks in Greenland ice are also known to have produced other atmospheric effects, such as haze or dry fog, dimming of the sun, and peculiar optical phenomena, as well as possible climatic cooling (*2*). These effects have been reported in Europe after large local eruptions, such as that of Laki (Iceland) in 1783 (*3*). In addition, very large eruptions at distant localities, like the 1815 explosion of Tambora (Indonesia), can produce similar atmospheric anomalies as far away as Europe and eastern North America (*4*). Historical records, therefore, provide a second source of information about distant volcanism. For many modern eruptions (those since A.D. 1500), reports of atmospheric phenomena have been compiled and described (*2, 5*). For earlier eruptions, however, no such compilation is available. We searched the extant European (and some Near Eastern) literature of the period 1500 B.C. to A.D. 1500 for accounts of atmospheric aftereffects and local volcanic eruptions that might have caused these aftereffects.

We compared years of major eruptions derived from historical sources (*6*) with years of the largest acidity peaks (> 4 μeq of $H^+$ per kilogram of ice) in Greenland ice reported by Hammer *et al.* (*1*). Our search of the literature was comprehensive only for the period 735 B.C. to A.D. 630; for the earlier and later years discussed, we were guided by the work of Hammer *et al.* (*1*) as to which periods to examine in detail. (Relevant reports on events before ~ 735 B.C. may be mostly legendary in any case.) Most eruption years were determined through the reported atmospheric aftereffects of the eruptions; in about half the cases, however, a specific volcano was pinpointed as the likely source (Table 1).

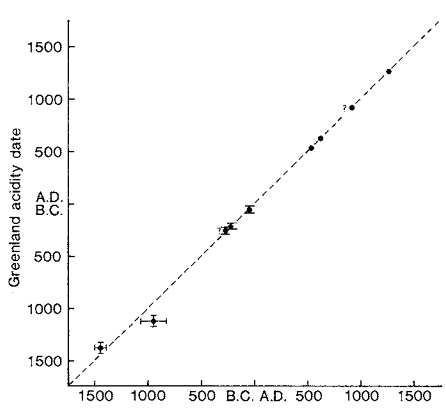


Fig. 1. Historical date (from reports of dry fog, weather, and volcanic eruptions and from radiocarbon dating) plotted against Greenland acidity date, for very large explosive eruptions, 1500 B.C. to A.D. 1500. Ice-core acidity information is not available for the period A.D. 44 to 540.

The table omits the period A.D. 44 to ~ 540, for which ice-core data are unavailable.

There is a strong correlation between the two sets of data on eruption years (Fig. 1). Since, however, our historical compilation can be considered a completely independent source only between 735 B.C. and A.D. 630, we have performed a significance test exclusively on this period, taking into account the known uncertainties in the ice-core dates that arise from the difficulty of counting the annual layers. We consider the probability $P$ of obtaining $s$ successes in $r$ random, simultaneous selections from a list of $n$ different years, of which $m$ specified years are of interest

$$P = \binom{m}{s}\binom{n-m}{r-s}\Big/\binom{n}{r}$$

The years of interest here are those of high acidity, including all years lying within ±1 standard deviation of the most probable year for each acidity signal; these years total $m$ = 200, with a gap (no ice-core data) between A.D. 44 and 540 omitted from the count and the years that overlap counted only once. Since we also have $n$ = 880, $r$ = 5, and $s$ = 4 (where $r$ and $s$ refer to the historical eruption years and we have conservatively not regarded 270 B.C. as a "success"), we obtain $P$ = 0.010. Thus the probability that the apparent correlation is accidental is negligible. We may conclude from this (i) that atmospheric aftereffects alone can be used to infer large volcanic eruptions, even in early historical times; (ii) that the largest acidity signals in old Greenland ice are due to these very same eruptions; and (iii) that early historical records can be used to date precisely the largest Greenland acidity signals and thereby help establish an accurate, premodern ice-core chronology. Our analysis strongly supports the conclusions of Lamb and Hammer (*2*) for the modern period and extends the time span of their analysis by many times.

According to the data in Table 1, European eruptions dominate the ice-core record. Even with the questionable 217 B.C. Vesuvius eruption not counted, five of the nine eruption years between 1500 B.C. and A.D. 1500 were times of great European eruptions: three in the Mediterranean area and two in Iceland. These results are partly understandable in view of Europe's (especially Iceland's) proximity to Greenland. Although the total of nine detected great eruptions does not represent the complete worldwide incidence of great eruptions during this period, it does reflect a

Table 1. Years of major volcanic eruptions determined by several different methods, from 1500 B.C. to A.D. 1500. There is a gap in the table (no ice-core data) between A.D. 44 and A.D. ~ 540. The survey of historical records is complete only between 735 B.C. and A.D. 630. Abbreviations: A, archeology and legend; D, dry fog; E, eruption column; F, distant ash fall; O, optical phenomena; R, radiocarbon; and W, weather.

| Largest Greenland acidity peaks | Historical data | | |
|---|---|---|---|
| Year* | Year | Volcano | Method |
| 1390 ± 50 B.C. | 1500–1400 B.C. | Thera (Greece) | A, R* |
| 1120 ± 50 B.C. | 950 ± 130 B.C. | Hekla (Iceland) | R* |
| 260 ± 30 B.C. | 270? B.C. | ? | W? |
| 210 ± 30 B.C. | 217–216 B.C. | Vesuvius (Italy)? | D, E?, O?, F? |
| 50 ± 30 B.C. | 44 B.C. | Etna (Italy) | D, W, E, O, F |
| A.D. 540 ± 10 | A.D. 536 | Rabaul (New Britain)? | D, W, R? |
| A.D. 623 ± 3 | A.D. 626 | (Mediterranean) | D, W, F |
| A.D. 934 ± 2 | A.D. 934? | Eldgjá (Iceland) | A,* W? |
| A.D. 1258 ± 1 | A.D. 1258 | ? | D, W |

*Hammer *et al.* (*1*).

continual and uniform sampling at one site, confirming that long-term time studies of historic explosive volcanism can be made.

Smaller European eruptions also seem to have left detectable signs in Greenland ice. Hammer *et al.* (*1*) published a complete record of "unambiguous" (> 1.5 $\mu$eq of $H^+$ per kilogram) acidity signals for the limited period 152 B.C. to A.D. 43. Our record of historical Mediterranean eruptions of moderate to large size (*6*) indicates that dates of known eruptions (which are all due to Mount Etna) are 141, 135, 126, 122–121, 50–49, 44, 36, and 32 B.C. and A.D. 38–40. To compare these dates with those of the acidities, it is necessary to adjust the zero-point of the ice-core dates (following our preceding analysis) so that the large acidity peak at 50 B.C. (±30 years) corresponds to the historical eruption year 44 B.C. when the great dry fog appeared in Europe (*7*). Allowing for a time lag of up to 1 year for the transport of acid aerosols from the Mediterranean to Greenland (*1*), we find that seven of the nine eruptions of Etna between 152 B.C. and A.D 43 appear to correlate exactly with Greenland acidity peaks. If we assume there are no errors in the ice-core dates other than the zero-point error (*8*), then by setting $m = 55$, $n = 195$, $r = 9$, and $s = 7$, we obtain $P = 0.002$ as the (very small) probability that so many coincidences could happen by chance. Hence a single volcano, Mount Etna, probably produced about 15 percent of the unambiguous acidity peaks between 152 B.C. and A.D. 43. Field studies, including approximate radiocarbon dating, confirm the volcano's greater explosivity during classical antiquity as compared with recent centuries (*9*). Mount Etna, moreover, releases an exceptionally large proportion of sulfur among its discharged gases (*10*), so that an Etnan eruption that is only moderately explosive by global standards could produce a quite noticeable sulfuric acid signal in Greenland ice. Tropospheric and stratospheric winds need not (though they possibly may) follow a favored route between the Mediterranean and Greenland, but little is known about this question (*11*).

The relative dominance of European eruptions in the ancient ice-core record contrasts with the relative unimportance of European eruptions in modern times (Fig. 2). We are able to suggest two reasons for this difference. First, Northern Hemisphere explosive volcanism outside Europe seems to have been significantly less vigorous during antiquity than in recent centuries, as Fig. 2 indicates; smaller eruptions appear to have followed the same trend, as indicated by the fact that, during the period 152 B.C. to A.D. 43, only 55 acidity peaks in Greenland ice exceed 1.5 $\mu$eq of $H^+$ per kilogram, whereas 82 acidity peaks do so from A.D. 1778 to 1972 (*1*). This trend does not seem to reflect greater difficulty in identifying and measuring the older ice layers and their acidities—problems which have reportedly been overcome (*1, 12*) (for example, seven acidity peaks > 4 $\mu$eq of $H^+$ per kilogram were detected for the eighth millenium B.C.). The statistics on known volcanic eruptions support the suggestion that large areas of the world can experience centuries-long periods of relative volcanic inactivity, only to return to a state of greater activity later (*13*). Second, it is possible that most of the largest explosive Northern Hemisphere eruptions outside Europe during antiquity were relatively poor in sulfur content, and hence are underrepresented in Greenland ice. In support of this idea, we note that, although the silica content of magma is easily measured and sulfur is not, the relative abundances of these two elements tend to be inversely correlated in known cases (*14*). Therefore, it is significant that the European volcanoes Etna, Laki, and Lanzarote (Canary Islands) have produced in modern times large lava-flow eruptions of low silica content, followed by strong acidity peaks in Greenland ice and dry fogs in Europe (*1, 2*), whereas the more explosive, high-silica eruptions of Bezymianny (Kamchatka) and Santa Maria (Guatemala) failed to produce large acidity peaks in Greenland ice (*1, 15*).

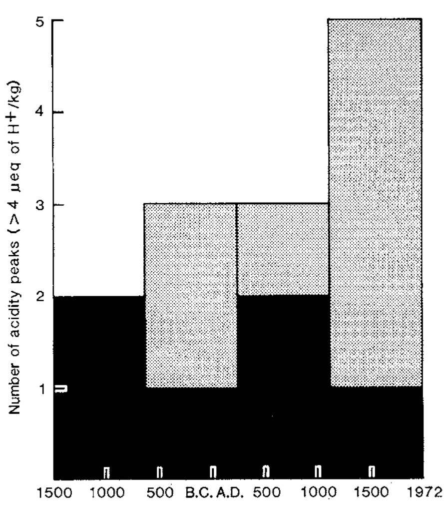


Fig. 2. Number of large acidity peaks in Greenland ice for four equal subdivisions (868 years each) of the historical period 1500 B.C. to A.D. 1972. Black area represents the acidity peaks attributed with some certainty to European volcanic eruptions. (Ice-core acidity information is not available for A.D. 44 to 540.)

Our results could be even more striking if a detailed ice core were available for the missing period A.D. 44 to 540. Vesuvius is known to have experienced cataclysmic eruptions in A.D. 79 and 469 to 474 (*6*). Unless these eruptions were sulfur-poor, they should be easily detected as large acidity spikes in Greenland ice. The eruption of A.D. 469 to 474 also appears to have generated an extensive dry fog in Europe (*6*).

So far, our findings, in conjunction with those of Hammer *et al.* (*1*), indicate that European volcanic eruptions produced at least six of the 13 largest acidity peaks recognized in Greenland ice during the past 3500 years. The record of European dry fogs and Greenland ice acidities will be useful in computing global atmospheric aerosol loading in studies of volcanic effects on climate.


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7. The effects of the eruption lasted 3 years and were observed also in China; the *Han shu* records (for May to June 43 B.C.): "The sun's color was pale blue and there were no shadows (on the ground). At noon exactly there were shadows but no brightness." The translation is taken from D. H. Clark and F. R. Stephenson, *Q.J.R. Astron. Soc.* **19**, 387 (1978).
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## Rates of Hydrothermal Reactions

Abstract. *The rates of reactions of silicates and aqueous fluids follow zero-order kinetics controlled by the reacting surface area with the rate constant given by the equation:* $\log k \simeq -2900/T - 6.85$, *where* T *is temperature and where* k *has the unit's gram-atoms of oxygen per square centimeter per second. This expression appears to hold for all silicates and for reactions involving dissolution, fluid production, or solid-solid transformations in the presence of a fluid of moderate to high* pH.

The rate relations of hydrothermal reactions are of considerable interest in geologic and materials sciences. A full understanding of these processes would enable us to predict weathering phenomena, reactions in geothermal and metamorphic systems, and the aqueous dissolution behavior of, for example, nuclear waste–bearing ceramics. In the course of reviewing published data (*1–19*) on reaction rates, we have discovered a general Arrhenius relation between reaction rate and temperature that appears to hold over temperatures from 25° to 710°C. It also holds for a large number of different silicate and related mineral species.

In the most detailed studies of mineral reaction rates (*1–7*), investigators have examined low-temperature dissolution phenomena of the type associated with weathering at the earth's surface. Such reactions may be represented as follows:

$$\text{mineral} + H_2O \rightarrow \text{aqueous solution} + \text{secondary solids} \quad (1)$$

Although many experimenters have found complex dissolution behavior, it has recently been shown (*4, 20, 21*) that apparent nonlinear relations are artifacts of sample preparation. Once fine-grained material is removed, dissolution follows a zero-order rate relation (*3–7*) controlled by the reacting surface area:

$$\frac{dm}{dt} = k_{\text{dis}} \quad (2)$$

The rate of removal of mass from the dissolving mineral ($dm/dt$, in moles per square centimeter per second) is therefore a constant at fixed temperature, pressure, and activities of solution species. The rate constant, $k_{\text{dis}}$, is, however, a function of temperature (*1, 7, 21*) and is *p*H-dependent in acidic solutions. Dissolution rates increase with increasing temperature (*1*) and with decreasing *p*H. At moderate to high *p*H [> 5 for feldspar at 25°C (*4, 20*)], however, the dissolution rate becomes *p*H-independent. The reason for the change in behavior reflects the nature of the rate-determining step. At high activities of $H_3O^+$ the hydrolysis process involves $H_3O^+$ in the rate-determining step, whereas at very low activities of this species undissociated solvent ($H_2O$) is the agent of hydrolysis (*20*). The extent of the *p*H-dependent region varies from phase to phase (*4, 20, 21*), presumably because of different interfacial properties and extents of $H_3O^+$ adsorption.

Most dissolution experiments have been performed in the temperature range from 0° to 90°C, with a few studies (*1, 2, 7*) extending up to 300°C. The higher temperature experiments were predominantly directed toward establishing equilibrium rather than toward estimating kinetic properties of reactions. Many of these "equilibrium" studies may be used to estimate reaction rates, provided certain assumptions are made about the nature of the rate-controlling process.

Let us consider a generalized high-temperature reaction involving solid and fluid phases:

$$\text{phase A} + \text{phase B} = \text{phase C} + \text{phase D} \quad (3)$$

Such reactions are generally studied in order to establish the temperature and pressure conditions of equilibrium between phases A, B, C, and D, one of which is typically a fluid. One of the most precise and successful methods of determining equilibrium in such cases (*8–19, 22*) is to use a fine-grained matrix of all but one of the product and reactant solids and a single crystal of the remaining phase. The experimental method requires only a few percent of fluid so that the production of fluid species is minimized. One then determines the direction of reaction by weighing the single crystal before and after the experiment to determine whether it is in the stable or unstable assemblage (Fig. 1). This method yields equilibrium at the point of zero weight change and, near equilibrium, an approximately linear relation between weight change and temperature (Fig. 1) (*23*). Linear behavior close to equilibrium is predicted by transition state theory (*20, 23–25*) which, under these circumstances, yields an equation of the form

$$\frac{dm}{dt} = \frac{k_r\,[\Delta S_r(T - T_{\text{eq}})]}{RT_{\text{eq}}} \quad (4)$$

where $k_r$ is the rate constant for the forward reaction at the equilibrium temperature $T_{\text{eq}}$ (in kelvins), $\Delta S_r$ is the overall entropy change of the reaction, and $R$ is the gas constant. Using Eq. 4, we have extracted $k_r$ values for a large number of single-crystal studies (*8–19*) performed at temperatures from 300° to 710°C (Fig. 2). Values of $\Delta S_r$ were computed from data of Helgeson *et al.* (*26*). Values of $\Delta S_r$ for reactions in $H_2O$–$CO_2$ were corrected for nonideal fluid behavior. The linear approximation breaks down far from equilibrium because of the temperature dependence of $k_r$ (*23*) (Fig. 1). Neverthe-

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# Volcanic Eruptions in the Mediterranean Before A.D. 630 From Written and Archaeological Sources

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Written and archaeological sources from the Mediterranean region have been exhaustively searched for evidence of historical volcanism before the year A.D. 630. Volcanic eruptions are identified here by two methods: direct observations, which give information about Mediterranean volcanoes, and indirect, atmospheric observations, which give at least the dates of very large explosive eruptions that occurred somewhere in the northern hemisphere. Seven or more very large explosive eruptions have been detected by these methods. Direct observations indicate great eruptions of Thera (fifteenth century B.C.), Etna (44 B.C.), and Vesuvius (217 B.C., A.D. 79, A.D. 472). Indirect observations imply great eruptions of northern hemisphere volcanoes in the years 217 B.C., 44 B.C., A.D. 472, A.D. 536, and A.D. 626. Some of the correlations with known Mediterranean eruptions may be accidental. It is found that atmospheric veiling and cooling were quite marked for about a year after the eruptions of 44 B.C., A.D. 472, A.D. 536, and A.D. 626 (relevant data are lacking for the other eruptions). If the A.D. 536 eruption was a very distant one (Rabaul, New Britain?), it may have been the most explosive in recorded history. There is independent evidence of the sizes of the eruptions that took place in these years: at least five of them coincide with the strongest acidity signals in Greenland ice for this period. In the case of the smaller eruptions, reliable (though necessarily incomplete) chronologies are presented for Etna, Vesuvius, and the other active Mediterranean volcanoes. Full documentation from the original sources is provided throughout.

## INTRODUCTION

The establishment of an accurate record of historic volcanism has long been recognized as important not only for analysis of volcanic eruption frequencies but also for the study of global climate change. Explosive eruptions are often able to inject large quantities of aerosols into the upper atmosphere, producing an apparent dimness of the sun and other unusual optical effects for periods ranging from months to years, over wide areas of the earth [*Symons*, 1888; *Lamb*, 1970; *Deirmendjian*, 1973; *Pollack et al.*, 1976]. Reports of these atmospheric aftereffects are in many cases the only evidence of major eruptions which were not observed directly or which were reported with insufficient detail to ascertain their explosive magnitude [*Lamb*, 1970].

Eruptions that produce such atmospheric phenomena are of considerable interest as possible perturbers of the earth's climate. Volcanic ash and volcanogenic sulfuric acid aerosols in the stratosphere absorb and backscatter some of the incoming solar radiation and hence are theoretically able to cool the earth's surface [*Pollack et al.*, 1976; *Hansen et al.*, 1978]. Studies of surface temperatures after large historic eruptions have identified a significant short-term (up to 3 years) hemispheric cooling of a few tenths of a degree Celsius [*Mass and Schneider*, 1977; *Taylor et al.*, 1980; *Self et al.*, 1981]. Longer-term cooling after large eruptions is also theoretically possible through positive feedback mechanisms like increased snow and ice cover [e.g., *Bray*, 1976].

Reports of other volcanically produced atmospheric phenomena such as widespread haze or "dry fog," unusual twilights, and associated optical effects that have been observed over the past several hundred years have been collected in several works (F. A. R. Russell in the work by *Symons* [1888]; *Heilprin* [1908]; and *Lamb* [1970]). Few such instances, however, have been reported for earlier historical times. One source of very early accounts is the literature of ancient Mediterranean civilizations. We have searched this literature in order to assemble a complete catalog of all very large volcanic eruptions reported from the Mediterranean region for the pre-A.D. 630 historical period. The cutoff date of A.D. 630 marks approximately the beginning of the Arabic era.

In the course of our research, we found that previously published catalogs of European volcanic eruptions contain many errors and omissions for the ancient period. A major part of our work, therefore, has been to replace the previous catalogs with a new one through a complete and critical reading of the original literature. To this end, we have investigated not only the major eruptions having demonstrable widespread significance but also the smaller eruptions, which had only local effects. Finally, we have been able to make inferences about the overall state of volcanic activity in the Mediterranean during the ancient historical period.

## PRECEDENTS AND PRELIMINARIES

Among the large number of previous catalogs of ancient Mediterranean volcanism, we have examined most carefully those compiled by the following authors: Catanti in the work by *Mecatti* [1752]; *della Torre* [1755]; *Capaccio* [1771]; *Recupero* [1815]; *Alessi* [1829, 1830]; *von Hoff* [1840]; *Daubeny* [1848]; *von Humboldt* [1850]; Scacchi in the work by *Roth* [1857]; *Phillips* [1869]; Bunbury and others in the work by *Smith* [1870]; *Lyell* [1875]; *Judd* [1875]; *Palmieri* [1880]; *Sartorius von Waltershausen* [1880]; *Nissen* [1883]; *Johnston-Lavis* [1884]; *Huelsen* [1894]; *Sapper* [1917, 1927]; *Chevallier* [1924]; *Alfano and Friedlaender* [1929]; *Radke* [1958]; *Georgalas* [1962]; *Imbo* [1965]; *Hirschboeck* [1980, unpublished catalog, 1976]; and *Simkin et al.* [1981]. None is an exhaustive or even completely independent catalog, and errors have multiplied with time. In each of the last three catalogs, for example, we find that for Mediterranean erup-



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tions within the period 1500 B.C. to A.D. 630, erroneous or omitted dates are more numerous than correctly cited dates by about 50%.

Our new search of the ancient literature (the equivalent of about a quarter of a million pages of modern English text) enables us to assess the real nature and completeness of the ancient volcanic record. Like others, we find that Biblical and Egyptian literature is generally too sparse and too ambiguous concerning natural phenomena to be really useful and is applicable mostly to the period before ca. 700 B.C. The Greek and Roman classical literature with which we are primarily concerned is fairly abundant but very heterogeneous in subject matter, quality, and coverage in time. For the medieval period up to A.D. 630, we have examined the Latin, Byzantine Greek, Syriac, and Armenian literature (the last two sources in translation), but the records are again quite sparse. Archaeological data, mostly bearing on the fifteenth century B.C. eruption of Thera and the A.D. 79 eruption of Mount Vesuvius, are useful to some extent. In spite of the limitations of the data at our disposal, most ancient reports of volcanic eruptions are not suspiciously linked to important contemporary historical events or restricted to the portent literature, and therefore they may be considered quite reliable. A detailed discussion of how much reliability can be placed in each ancient author and his sources, and of how dates are assigned to ancient authors and to the events they describe, is beyond the scope of this article; but a good reference for this kind of information is the *Oxford Classical Dictionary*.

It is clear that a complete record of ancient volcanism cannot be put together from the surviving fragments of ancient texts. Nevertheless, in the case of the most explosive eruptions, having the kind of widespread and obvious atmospheric effects mentioned earlier, the record is probably very nearly complete for the time period ca. 700 B.C. to A.D. 630, at least in Europe. For somewhat smaller eruptions, we estimate the following time intervals within which near completeness of the eruption record can be assumed: for Etna, 696–425 B.C. (from Thucydides' explicit testimony) as well as at least 141–32 B.C. (from the detailed annual lists of Italian prodigies, or unusual natural phenomena, provided by Julius Obsequens, Cassius Dio, and Appian); for Vesuvius, ca. 200 B.C. to A.D. 79 (from Dio's explicit testimony); and for Thera, at least 199 B.C. to A.D. 77 (from Pliny the Elder's explicit testimony). For other times, other volcanoes, and smaller eruptions we are at the mercy of the accidents of manuscript survivals. It must always be kept in mind as well that the Greeks did not colonize Italy until ca. 750 B.C. (Sicily ca. 735 B.C.), that is, the time of Homer, and that the earliest extant Greek history was not written until ca. 430 B.C. Likewise, detailed Roman records for the period before the sack of Rome by the Gauls in ca. 390 B.C. were generally unavailable to the first Roman historians, who were writing ca. 200 B.C. Prior to these critical dates, Greek and Roman history must be regarded as largely legendary.

A word about our citation of historical references is necessary. Ancient authors and their works are cited here directly in the text. Titles, however, are provided only where necessary to eliminate ambiguity or obscurity. Chronological order of authors cited together (or of their sources if known) is strictly followed; dates are normally explicitly provided in most cases. English translations of the texts are either our own or else adaptions from standard versions, where these follow closely the original texts.

The following abbreviations are used: *CIL*, *Corpus Inscriptionum Latinarum*; *MGH*, *Monumenta Germaniae Historiae Auctores Antiquissimi*; *PG*, Migne's *Patrologia Graeca*; *PL*, Migne's *Patrologia Latina*; Bollandists, Bollandist Fathers' *Acta Sanctorum*.

## MAJOR EXPLOSIVE ERUPTIONS

### *Etna: 44 B.C.*

Surviving literature from the Augustan age (27 B.C. to A.D. 14) and slightly earlier relates that after the assassination of Julius Caesar on March 15, 44 B.C. there was a dimming of the sun that cannot be attributed today to a solar eclipse (Mark Antony in Josephus, *Jewish Antiquities* 14.309; Vergil, *Georgics* 1.463–468; Tibullus 2.5.75–76; Ovid, *Metamorphoses* 15.785–790; Manilius 2.595). Although Mark Antony and Vergil were actually living in 44 B.C., it is not entirely certain that their vague allusions refer to anything other than the darkness of a violent thunderstorm that followed immediately after Caesar's murder (Dio, *Roman History* 44.52.1; see also the similar allusions made by the fourth century authors Servius, *Commentary on Vergil's Georgics* 1.466, and pseudo-Aurelius Victor, *On Famous Men* 78). However, Tibullus, who was a much younger poet of the Augustan age, records more specifically a phenomenon that can be dated to the same year from internal evidence within his poem:

> Light departed from the Sun himself, and the cloudy year saw him yoke dim horses to his chariot.

Fortunately, there exist better historical authorities from later ages, who attest to this phenomenon even more explicitly. Their ultimate source was most likely Livy (born ca. 59 B.C.), who covered this period in the now lost Books 116 and 117 of his Roman history. One of these authorities, Pliny the Elder (A.D. 77) (*Natural History* 2.98), informs us

> Portentous and protracted eclipses of the sun occur, such as the one after the murder of Caesar the dictator and during the Antonine war which caused almost a whole year's continuous gloom.

Similar reports can be found in Dio (third century A.D.) (45.17.5) and in Obsequens (fourth century A.D.?) (*Book of Prodigies* 68). However, the fullest account is provided by Plutarch (ca. A.D. 100) (*Caesar* 69.3–4):

> Among events of divine ordering there was . . . after Caesar's murder . . . the obscuration of the sun's rays. For during all that year its orb rose pale and without radiance, while the heat that came down from it was slight and ineffectual, so that the air in its circulation was dark and heavy owing to the feebleness of the warmth that penetrated it, and the fruits, imperfect and half ripe, withered away and shrivelled up on account of the coldness of the atmosphere.

This account is very similar to the classic description by Benjamin Franklin of the "dry fog" that persisted over Europe at the time of the 1783 eruption of the volcano Laki in Iceland [*Lamb*, 1970, p. 433]. Such a dimming of the sun (and moon) has been reported by naked-eye observers after many large volcanic eruptions and has been consistently noticed and reported after explosive eruptions more than have any other unusual optical phenomena. Reports of "dry

fogs" in Europe usually follow relatively local eruptions (southern Europe, Iceland, Canary Islands, etc; see *Lamb* [1970, Appendix I]), although the great Tambora (Indonesia) event in 1815 was followed by reports of dry fog in Europe and eastern North America [*Post*, 1977]. This suggests that the eruption that produced the phenomena of 44 B.C. in Italy might have been a European eruption.

Plutarch's mention of a crop failure in 44 B.C. probably explains Tibullus' (2.5.84–86) reference to a renewed abundance of grain and grapes after the gloomy year 44. However this may be, Cicero, writing in early June of 44, notes that such important men as Brutus and Cassius were urgently appointed grain commissioners by the senate (Cicero, *Letters to Atticus* 15.9–12; see also the second century author Appian, *Civil Wars* 3.6, 3.35, 4.57). Later, on September 2, he refers to a famine that is "in part present and in part impending" (*Philippics* 1.6.13). Clearly, more may be implied by Cicero's remarks than just the economic and political consequences of the civil war. The following year an oracle predicted that grain would not be harvested in the coming summer (Obsequens 69). The fact that this prediction was recorded suggests that it may have come true. On the other hand, a letter from Asinius Pollio to Cicero (in Cicero, *Letters to his Friends* 10.33) proves that grain was plentiful at least around Cordova, Spain, in June of 43. All we can safely conclude is that the crops failed in 44 and may have failed also in 43, at least in some parts of the Roman world.

Several workers [*Lamb*, 1970; *Post*, 1977; *Stommel and Stommel*, 1979] have proposed that disastrous crop failures in Britain and northeastern North America following cold and rainy summers may have been related to explosive volcanic eruptions, for example, Tambora (Indonesia) in 1815 and the series of eruptions in various parts of the world in the 1690's. *Lamb* [1970] has noted further that the three coldest summers in the northeastern United States between 1780 and 1960 were years of considerable volcanic dust veils.

The hazy condition of the atmosphere described by Plutarch had other reported effects. Although no contemporary account exists, Obsequens (68) reports the tradition:

> When at the third hour of the day [about 9 a.m.] he entered Rome, surrounded by a huge crowd, the sun, enclosed within a small circle of clear and calm sky, surrounded Octavius with the end of an arc such as the rainbow usually displays in the clouds .... [At another time] three suns shone, and around the lowest sun a wreath like the wreath of heads of grain flashed into view surrounding it.

With generally less detail, other authors have described both the remarkable solar halo (Velleius Paterculus 2.59.6; Seneca, *Natural Questions* 1.2.1; Pliny the Elder 2.98; Suetonius, *Augustus* 95; Dio 45.4.4; Orosius, *Against the Pagans* 6.20; John Lydus, *On Portents* 10b) and the pair of mock suns (Pliny the Elder 2.99; Dio 45.17.5; Eusebius-Jerome, *Chronicle*, Olymp. 184). Appian (*Civil Wars* 4.4) mentions "fearful signs" around the sun in the following year 43, and three authors refer to a display of mock suns again in 42 (Pliny the Elder 2.99; Dio 47.40.2; Obsequens 70).

The unusual atmospheric phenomena of 44–42 B.C. are similar to those that are known to follow large explosive volcanic eruptions which inject aerosols into the stratosphere. Increases in the aerosol optical depth of the stratosphere give rise to a decrease in the direct solar beam [*Humphreys*, 1940; *Lamb*, 1970; *Hoyt*, 1979], and scattering by dust particles and sulfuric acid drops leads to optical phenomena such as a blue or green color to the sun or moon, unusual twilights, mock suns, and Bishop's rings (a colored aureole-corona complex within a circular region around the sun or moon, with a visual radius of 20°–30°) [*Symons*, 1888; *Heilprin*, 1908; *Deirmendjian*, 1973]. Such unusual optical phenomenon have been reported after many great volcanic eruptions, for example, Krakatau in 1883, the 1902–1903 series of eruptions (including Santa Maria and Pelée), Katmai in 1912, and Agung in 1963.

As for the cause of the unusual atmospheric conditions in 44–42 B.C., volcanic aerosols from an eruption of Mount Etna in 44 B.C. are one possibility. Vergil (*Georgics* 1.466–473) relates

> After the death of Caesar . . . how often we saw Etna flooding out from her burst furnaces, boiling over the Cyclopean fields, and whirling forth balls of flame and molten stones.

Servius (*Commentary on Vergil's Georgics* 1.472) says in explanation of this passage

> As Livy relates, before Caesar's death such flame flowed down from Mt. Etna that not only the neighboring cities but even the city of Regium were blasted by it.

Livy's more authoritative date, being set in an annalistic history, is to be preferred to Vergil's, although the word quotiens ("how often") in Vergil may imply a continuing series of eruptions. Probably, the primary eruption occurred early in 44. Its destructive range was at least 70 km, since apparently a hot ash fall crossed the Straits of Messina and struck what is now known as Reggio di Calabria. Appian (*Civil Wars* 5.114) confirms that lava flowed into the sea, which is 18 km from the summit, and earthquakes were reported as far away as Rome (Vergil, *Georgics* 1.479; Ovid, *Metamorphoses* 15.798; Dio 45.17.4; Obsequens 68). In the *Aeneid* (3.571–582), Vergil supplies further details of the eruption:

> Etna thunders with terrifying crashes, and now hurls forth to the sky a black cloud, smoking with pitch-black eddy and glowing ashes, and uplifts balls of flame and licks the stars—now violently vomits forth rocks, the mountain's uptorn entrails, and whirls molten stones skyward with a roar, and boils up from its lowest depths .... Mighty Etna . . . from its burst furnaces breathes forth flame; and . . . all Sicily moans and trembles, veiling the sky in smoke.

Some authors, both ancient and modern, have suggested that this vivid description is a mere reworking of Pindar's description (probably eyewitness) of an eruption in ca. 475 B.C. (*Pythian Odes* 1.19–28). However, its originality is confirmed by the similarity of its language to that in the cited passage of *Georgics*, together with Servius' commentary, as well as by the significant differences of content from Pindar's poem, which were pointed out originally by the critic Favorinus in the second century A.D. (Aulus Gellius 17.10; Macrobius, *Saturnalia* 5.17). Finally, we have the testimony of Pliny the Elder (2.234), undoubtedly referring to the same eruption:

> Etna . . . is so hot that it belches out sands in a ball of flame over a space of 50 to 100 [Roman] miles at a time.

The range mentioned for the "ball of flame" (probably a hot ash fall) corresponds to about 75–150 km, which considerably exceeds the volcano's normal range of about 30 km, also given by Pliny (3.88).

Modern field studies of Etna have uncovered a stratigraphic record of major past explosive activity [*Keller et al.*, 1978; *Guest and Duncan*, 1981] that ended during the early Middle Ages [*Kieffer*, 1979]. The few available radiocarbon dates in the period of interest (890 B.C., A.D. 110, 140, and 190, all with mean errors of about ±100 years) cannot be definitely reconciled with the dates of any known historical eruptions. The lack of an accurate empirical dating method renders mostly conjecture, in our opinion, the many attempts [e.g., *Romano and Sturiale*, 1981] to correlate the undetailed (but well dated) ancient eruption reports with specific volcanological features in the case of such a continuously active volcano as Etna. Nonetheless, lava flows are reported in ancient times to have traveled east to the sea, west to the Simeto River, and south to Catania (*Aetna* 487, 508; Table 1), distances which agree well with modern observations [*Imbo*, 1965]. A fairly large recent eruption of Etna that bears some resemblance to the 44 B.C. event occurred in 1886. The eruption column was estimated to be 14 km in height, while haze and mist following this eruption blocked out the sun in Sicily; within 2 weeks the haze had spread throughout Italy [*Lamb*, 1970].

Further evidence of a great 44 B.C. eruption comes from a time record of acidity in a Greenland ice core analyzed by *Hammer et al.* [1980]. A strong 3-year acidity peak was dated by them at about 50 ± 30 B.C. and has been confirmed at ca. 40 B.C. in another ice core by *Herron* [1982]. Hammer et al. suggested that it is due to one of the largest volcanic eruptions in the northern hemisphere since the last glaciation. They proposed that if the heavy sulfuric acid fallout in Greenland were to be ascribed to Etna, the magnitude of the eruption and its impact on Roman society would have been so great that there would undoubtedly be geological and historical evidence. We believe that the historical evidence assembled in this paper supports the occurrence of a major explosive Etnan eruption in 44 B.C. Etna's known sulfur richness [*Wadge and Guest*, 1981] also suggests that a very large eruption of this volcano could have produced the observed acidity peak in Greenland ice.

Of course, we realize that the acidity signal in the Greenland ice as well as the atmospheric effects of the time may have been the result of one or more remote and as yet unknown eruptions. Alternatively, a known but distant eruption that might be relevant is the very large Sunda (Indonesia) eruption, which on archaeological grounds is estimated to have occurred at about the time of Christ [*van Bemmelen*, 1971]. Another possibility is the Alaskan White River (north lobe) eruption which has been radiocarbon dated at about A.D. 60 ± 100 [*Lerbekmo et al.*, 1975].

### *Vesuvius: 217 B.C., A.D. 79, and A.D. 472*

We present next the literary evidence for another major volcanic eruption, one that occurred in 217 B.C. In that year the Roman pontiffs apparently recorded a dry fog, as "the sun's disk seemed to be diminished" (Livy 22.1.9).

It was also noted in 217 B.C. that a shower of "glowing stones," suddenly appearing from the south (Silius Italicus 8.650-651), had fallen at the town of Praeneste, near Rome (Livy 22.1.9; Plutarch, *Fabius Maximus* 2.3), while at Capua, 30 km north of Naples, there had been "the appearance of a sky on fire" (Livy 22.1.12). Round glows in the sky and a sudden darkening of the sun seem also to have been observed from the east coast of Italy near Mount Gargano (Livy 22.1.9; Silius Italicus 8.632-633). A record number of violent earthquakes, too, had been felt throughout Italy in that year (Coelius Antipater in Cicero, *On Divination* 1.78; Livy 22.5.8; Pliny the Elder 2.200; Silius Italicus 5.611–633, 8.627–649; Plutarch, *Fabius Maximus* 3.2; Florus, *Epitome* 1.22.14). But most significantly of all, Mount Vesuvius is said by the first century A.D. epic poet Silius Italicus (*Punica* 8.653–655) to have erupted:

> Vesuvius also thundered, hurling flames worthy of Etna from her cliffs; and the fiery crest, throwing rocks up to the clouds, reached to the trembling stars.

Although Silius included this information in a long list of prodigies for the year 216, some of these prodigies appear also in Livy's (22.1.8–13) list for the year 217, which should be preferred as the correct date. The simile with Mount Etna is of course derived from Vergil and at first sight makes this prodigy suspect. But a later passage (Silius Italicus 12.152–154) details the aspect of the Campanian mountain in 215 B.C.:

> Hannibal is shown Mt. Vesuvius, where fire has eaten away the rocks at its summit, and the wreckage of the mountain lies all around, and the discharge of stones seeks to rival the death dealt by Etna.

This passage is conspicuously free of the mythological associations that Silius attaches in his poem to other volcanoes.

In the Augustan age, Diodorus Siculus, Vitruvius, and Strabo, while recognizing Vesuvius's volcanic character, thought that the mountain had been extinct since prehistoric times. But Strabo (1.2.18, 5.4.8) does inform us that the summit in his day was barren and ash-colored, and Diodorus Siculus (4.21.5) and Vitruvius (2.6.2-3) agree that the mountain still displayed in their day the signs of earlier fire. These facts suggest that the last eruption had occurred in the not too distant past, which would support Silius' testimony. There is also the more general argument that according to modern critics, Silius' historical and geographical facts, whenever they can be checked, usually hold up [*Nicol*, 1936]. Furthermore, the independently reported distant effects of the eruption closely resemble the ones observed after the more famous eruption of A.D. 79.

Discussion of the more important A.D. 79 eruption, which buried Pompeii, Herculaneum, and other towns under thick layers of ash, pumice, and lahars, must be based principally on the two detailed accounts given by Pliny the Younger (*Letters* 6.16, 6.20). Although Pliny's accounts are too long to be quoted here, many geological texts present them in full [e.g., *Bullard*, 1976]. Countless authors have attempted to reconstruct in detail the sequence of events occurring during the eruption; for example, strong evidence for the development of two nuées ardentes has recently been found by *Sigurdsson et al.* [1982]. Our principal contribution here will be to provide a complete guide to the numerous other ancient authorities, to draw attention to the uncertainty of the key dates, to determine the approximate configuration of the volcano just before the eruption, and to discuss the eruption's wider physical consequences.

It seems to be almost universally believed that prior to its massive outburst, Mount Vesuvius had the form of a single truncated cone. When the top of the volcano collapsed or

blew off, it left only the steep ridge of the present Mount Somma to the north and east. This belief rests primarily on two descriptions given by Strabo and Dio, supplemented by a Pompeian wall painting.

"The summit of Mt. Vesuvius is in large part flat," observed Strabo (5.4.8) in the first century B.C. Dio (66.21.1), writing in the third century A.D., stated that "once Mt. Vesuvius was equally high at all points." And the Pompeian wall painting [*Kusch*, 1960, Plate 2] does show a single (though not truncated) peak. But consider the context of this evidence as well as some further information. Strabo has also mentioned "hollows and valleys" and evidence of "craters of fire in earlier times" at the summit, while Dio appears to be making only a reasoned conjecture about the prehistoric condition of the mountain. Dio's additional remarks about the outlying peaks (Mount Somma) retaining their original height and supporting abundant vines are very similar to the descriptions of that part of Mount Vesuvius occupied by Spartacus and his troops in 73 B.C., although these descriptions have admittedly come down only in post-A.D. 79 authors (Frontinus, *Stratagems* 1.5.21; Plutarch, *Crassus* 9.1–2; Florus, *Epitome* 2.8.4). The Pompeian wall painting mentioned above depicts Vesuvius in a very peculiar montage with explicitly mythological subjects. Therefore a number of more relevant wall paintings showing more realistic landscapes should certainly also be considered. Two of them, one from Pompeii [*Trevelyan*, 1976, Plate 59] and the other from Herculaneum [*Kusch*, 1960, plate on p. 5], show different views of Vesuvius as seen from the neighborhood of Naples, but two mountain peaks. Two other wall paintings from Pompeii [*Spinazzola*, 1953, Plates 859 and 861] display almost identical views of Vesuvius as seen from Herculaneum, but three peaks (the peak farthest to the left in one of these wall paintings, which seems to be an abridged copy of the other, is almost entirely cut off). Modern photographs confirm that the Somma-Vesuvius massif appears dominantly single, double, and triple, as seen from Pompeii, Naples, and Herculaneum, respectively [e.g., *Trevelyan*, 1976, Plates 3 and 4; *Kusch*, 1960, Plate 3]. Although the height of the main cone of Vesuvius has varied considerably over the centuries, the basic profile of the mountain just before the A.D. 79 eruption seems not to have been radically different from its present shape.

Although the year of the A.D. 79 eruption is well established (Dio 66.17–26; Eusebius-Jerome, Olymp. 214; Zonaras, *Annals* 11.18), the month and day are not (Pliny the Younger, *Letters* 6.16). The two-day event probably occurred during August 24–25, but later dates (perhaps as late as November 1–2) can be argued from the variant text readings [e.g., *Doering*, 1843]. The eruption is known to have been closely observed from Misenum by Pliny the Younger, who afterward made detailed inquiries about it from other witnesses. Two or three decades later, he wrote for the historian Tacitus a detailed description of the whole event (including the death of his uncle Pliny the Elder) as seen from different points around the Bay of Naples (Pliny the Younger, *Letters* 6.16, 6.20). The eruption may well also have been observed by the poet Statius (*Silvae* 2.6.61–62, 3.5.72–73, 4.4.78–86, 4.8.5, 5.3.205–208) and possibly by Silius Italicus, who often resided in Campania. In addition to the devastating local effects of this eruption, we are told by later historians that the sun was darkened at Rome for many days and that ash fell there and in even more distant places like Tripolitan Africa, Egypt, and Syria (Dio 66.23; Procopius, *Wars* 6.4.27; Zonaras 11.18) and perhaps farther in the east (Silius Italicus 17.592–596). The notoriety of this eruption in antiquity is attested by the numerous references or allusions to it made by other persons who were living at the time (Josephus, *Jewish Antiquities* 20.144; Valerius Flaccus 3.208–209, 4.507–509; Tacitus, *Histories* 1.2, *Annals* 4.67; Martial, *Epigrams* 4.44; Plutarch, *On the Pythian Responses* 398E, *On the Late Vengeance of the Deity* 566E; Suetonius, *Titus* 8, *On Famous Men*, *s.v.* Pliny; *Sibylline Oracles* 4.130–136) and by many later authors as well (Marcus Aurelius 4.48; Tertullian, *To the Nations* 1.9, *Apology* 40, *On Penitence* 12, *On the Pallium* 2; Dio 66.21–24; Eusebius-Jerome, Olymp. 214, 221; *Epitome of Caesars* 10; Orosius 7.9). Marcus Aurelius (ca. A.D. 175) is the earliest known author to mention the destroyed cities by name and to refer to them as "dead" cities.

It is noteworthy that the eruption was not only accompanied but also preceded by many local earthquakes (Pliny the Younger, *Letters* 6.16, 6.20; Dio 66.22), especially one or two very violent ones at dates that are uncertain but must lie between A.D. 62 and 64 (Seneca, *Natural Questions* 6; Tacitus, *Annals* 15.22, 15.34; Suetonius, *Nero* 20; *CIL*, *10*(1), 846, 1406). This eruption and the one of 217 B.C. seem to have been associated in a similar way with numerous ground shocks.

Another major eruption of Vesuvius occurred in the year A.D. 472, according to Count Marcellinus (*Chronology*, Mommsen, *MGH*, *11*, 90), a reliable writer of the sixth century,

> Vesuvius, a burning mountain of Campania, seething with internal fires, vomited up its completely consumed inner parts and turned day into night, covering the whole surface of Europe with a fine dust. Every year on November 6, the people of Constantinople celebrate the memory of these terrifying ashes.

Although there is no extant contemporary account of this prodigious event, other authors of the sixth century also mention various aspects of it (Procopius, *Wars* 6.4.27; John Lydus, *On Portents* 6; Victor Tonnennensis, *Chronology*, Mommsen, *MGH*, *11*, 195; Theodorus Lector, *Ecclesiastical History*, Migne, *PG*, *86*(1), 177; John Malalas, *Chronography*, Migne, *PG*, *97*, 553). According to Theodorus Lector, "fiery clouds" had been observed in the sky before the ash fell. John Malalas gives the final depth of ash on the roofs of Constantinople as "one palm's breadth" (a standard unit, normally equal to ~8 cm). George Cedrenus (eleventh century) (*Histories*, Migne, *PG*, *121*, 668) adds the information that the ash fall began around noontime. Many other Byzantine chroniclers record both the fiery clouds and the depth of the ash. Somewhat different years, however, are noted for the date. John Lydus gives "the time of Zeno" (A.D. 474–491); an anonymous seventh century chronicler (*Easter Chronicle*, Migne, *PG*, *92*,, 828), A.D. 469; Theodorus Lector and George Cedrenus, A.D. 473; Theophanes Confessor (tenth century) (*Chronography*, Migne, *PG*, *108*, 300), A.D. 474; and Victor Tonnennensis, A.D. 513. A passage from Count Marcellinus (p. 97, Mommsen), however, corrects the date given by Victor Tonnennensis. (These dates are all referred to A.D. 474 as the year of the emperor Leo I's death.) Late Near Eastern chroniclers wrongly give the date (if it refers to the same ash fall) as A.D. 429/430 (*Edessan Chronicle* 57; *Chronicle to A.D. 846*, p. 210,

Chabot; Michael the Syrian, *Chronicle* 8.176, Chabot). Finally we have a contemporary report from Portugal for one of the years during the emperor Anthemius' reign (A.D. 467–472) (Hydatius, *Chronicle*, Mommsen, *MGH*, *11*, 35):

> At this same time, there was a year of exceptional harshness, extending through winter, spring, summer, and autumn, when a great change took place in the atmosphere and in all the fruits.

The 8-cm thickness of ash reported to have fallen on Constantinople (1200 km east of Vesuvius) is quite extraordinary if attributed to the Italian volcano. By comparison, the huge explosive eruption of Tambora in 1815 put less than 2.5 cm of ash at Batavia, about 1300 km from the volcano [*Petroeschevsky*, 1949]. The depth of ash reported from Constantinople may refer only to a palm's thickness of ash, or perhaps to wind-driven drifts, or, possibly, to an unrelated ash fall which accompanied a great fire in Constantinople that occurred at about the same period (for evidence of the chronological confusion, see John Malalas, col. 553, Migne; *Easter Chronicle*, cols. 821, 829, Migne; Leo the Grammarian, *Chronography*, p. 114, Bekker).

Modern studies of pumice fall deposits that are widely dispersed over the areas to the northeast, east, southeast, and south of Mount Vesuvius have uncovered evidence for at least eight large plinian eruptions [*Lirer et al.*, 1973; *Delibrias et al.*, 1979; *Rosi et al.*, 1980]. The sequence and chronology of these eruptions, however, must be somewhat incomplete because of the poor exposure and frequent lack of superposition of the deposits, the paucity of datable material, and the similarity of the pumice deposits of different eruptions. Only three pumice layers have been studied in any detail. The Pollena pumice, dispersed east-northeast and radiocarbon dated to about A.D. 360 ± 60, may have originated in the A.D. 472 eruption. The Pompeii pumice, with an axis of dispersal toward the southeast, has been correlated with the A.D. 79 eruption. An older deposit, the Avellino pumice, dispersed toward the northeast, has been radiocarbon dated to the second millenium B.C.

If the 217 B.C. eruption of Vesuvius was a large plinian event, there should be corresponding pumice fall deposits widely dispersed in surrounding areas. The regional geologic studies now available have not detected the predicted layer of pumice. Perhaps further sampling in the areas to the east or northeast of Vesuvius (the inferred direction of dispersal of the 217 B.C. ash) is required. However, an explosive event need not have ejected a large amount of pumice. Archaeological studies suggest that Pompeii, to the southeast, escaped essentially unscathed. But it is tempting to speculate that the large change in Pompeian art style at ca. 200 B.C. [*Van Buren*, 1952] may have been related to possible earthquake damage to the city in 217 B.C. A similar change in art style definitely occurred after the earthquakes of A.D. 62–64.

More recent eruptions of Vesuvius, though of lesser magnitude, have also produced wide-ranging atmospheric effects analogous to those of the ancient eruptions [*Lamb*, 1970; *Symons*, 1888]. For example, after the 1717 eruption, there was an ash-produced darkness 160 km from the volcano. The 1813 and 1822 eruptions were followed by dimming of the sun in northern Italy, whereas the 1831 eruption of Vesuvius preceded an extraordinary dry fog that persisted throughout Europe and North Africa and was reported as far away as Siberia and the United States. The haze in the latter case may have been only partly due to Vesuvius; large eruptions in the Mediterranean Sea (Giulia) and the Philippines (Babuyan) were also reported in 1831. The most recent explosive eruption of Vesuvius in 1944 caused darkness at Bari, 200 km from the volcano.

*Unknown Volcanoes: A.D. 536 and A.D. 626*

Four historians who were living in the year A.D. 536 have left surviving accounts of that extraordinary year. Procopius (*Wars* 4.14.5) writes

> And it came about during this year that a most dread portent took place. For the sun gave forth its light without brightness, like the moon, during this whole year, and it seemed exceedingly like the sun in eclipse, for the beams it shed were not clear nor such as it is accustomed to shed.

John Lydus (*On Portents* 9c) confirms the account:

> The sun became dim . . . for nearly the whole year . . . so that the fruits were killed at an unseasonable time.

In the Syriac chronicle associated with the name of Zacharias of Mytilene, we read (*Chronicle* 9.19, 10.1, Hamilton and Brooks)

> The earth [at Constantinople] with all that is upon it quaked; and the sun began to be darkened by day and the moon by night, while the ocean was tumultuous with spray (?) from the 24th of March in this year till the 24th of June in the following year . . . . And, as the winter [in Mesopotamia] was a severe one, so much so that from the large and unwonted quantity of snow the birds perished . . . , there was distress . . . among men . . . from the evil things.

The severity of the winter of 536/537 in Mesopotamia is independently attested by another contemporary writer, John of Ephesus (*Ecclesiastical History*, pp. 297–298, Land). A very late chronicler, Michael the Syrian (twelfth century), whose source was probably John of Ephesus, provides a little further information (*Chronicle* 9.296, Chabot):

> There was a sign in the sun the like of which had never been seen and reported before . . . . The sun became dark and its darkness lasted for eighteen months. Each day it shone for about four hours, and still this light was only a feeble shadow. Everyone declared that the sun would never recover its full light. The fruits did not ripen and the wine tasted like sour grapes.

No significant additional information about this event is provided by other late chroniclers who mention it. It should be noted that the Byzantine annalists give the duration of dimming of the sun as close to one year, whereas the chroniclers slightly farther south mention 18 months. This suggests a volcanic aerosol cloud that may have slowly spread northward.

Whether a European volcanic eruption provided a source of aerosols that obscured the sun in A.D. 536–537 cannot be determined with any certainty. Procopius, who was present in Campania early in 536, says (*Wars* 6.4.21-28)

> At that time the mountain of Vesuvius rumbled, and though it did not break forth in eruption, still because of the rumbling it led people to expect with great certainty that there would be an eruption . . . . When the mountain gives forth a rumbling sound which resembles bellowing, it generally sends up not long

afterward a great quantity of ashes .... Formerly this rumbling took place, they say, once in a hundred years or even more, but in later times it has happened much more frequently.

The prior eruptions of Vesuvius that are specifically known to us from ancient reports occurred in (or in about) the years 217 B.C., A.D. 79, A.D. 202, A.D. 472, A.D. 505, and A.D. 512. Perhaps shortly after Procopius moved north to Rome from the neighborhood of Vesuvius, the mountain did erupt. But in that case it is strange that Procopius would not have eventually heard about the eruption or experienced an ash fall at Rome and mentioned it in his history (see also *Wars* 8.35.1–6).

The last ancient record of dimming of the sun, in A.D. 626, is found in Michael the Syrian (*Chronicle* 11.409, Chabot):

In the year A.D. 626 the light of half the sphere of the sun disappeared, and there was darkness from October to June. As a result people said that the sphere of the sun would never be restored to its original state.

The meaning seems to be that the intensity of the sun, with or without an apparent change of diameter, diminished by about one half (see also Bar-Hebraeus, *Chronography* 10.96, Budge). George the Monk (tenth century) (*Chronology*, Migne, *PG*, *110*, 828), referring to the year A.D. 626 (or possibly A.D. 618), says that "the sun became dim; moreover, ashes rained down." The context of an identical passage by Michael Glycas (fifteenth century) (*Annals*, Migne, *PG*, *158*, 516) indicates that the ash fall was reported at Constantinople. Could it have been due to an eruption of Vesuvius or of some other Mediterranean volcano? A very late Irish chronicle, *Annals of Ulster*, mentions that the year A.D. 624 (wrongly for A.D. 626?) was "dark." The only possible contemporary notice is a Byzantine allusion to an unusual "darkness" at some time not long before the year A.D. 628 (George of Pisidia, *Heraclias* 1.81). According to several of the Near Eastern chroniclers, unusually cold winters occurred around this time, although none can be assigned specifically to A.D. 626/627.

*Hammer et al.* [1980] have reported an acidity signal in Greenland ice at A.D. 623 ± 3, which is in good agreement with our historical date for the dry fog. They have also noted that in a new ice core from Greenland, another strong acidity signal can be preliminarily dated at A.D. 540 ± 10, which *Herron* [1982] confirms (giving ca. A.D. 535). Hammer et al. have suggested that this latter signal may be a result of the large Alaskan White River (east lobe) eruption, radiocarbon dated at about A.D. 700 ± 100 [*Lerbekmo et al.*, 1975]. We believe, however, that the White River eruption is more likely to be represented in Greenland ice by the acidity peak measured at A.D. 757 ± 3. From our historical evidence for an intense Mediterranean dry fog in A.D. 536, we suggest that the eruption detected by Hammer et al. and Herron may have occurred in that year. It was probably a distant eruption; Rabaul, New Britain, radiocarbon dated at about A.D. 540 ± 90, is a possible candidate [*Heming*, 1974]. If so, it could have been the greatest aerosol-producing eruption in recorded history.

### *Thera: Fifteenth Century B.C.*

A large volcanic eruption of Thera (Santorini) in the Aegean Sea occurred in the fifteenth century B.C. Its possible role in the destruction of Minoan civilization on Crete was first suggested on geologic grounds by *Marinatos* [1939], while, as early as 1909, *Frost* [1939] argued that Plato's lost island of Atlantis was the Crete of Minoan times. Further literary, archaeological, and geological investigation has amplified and solidified these ideas [e.g., *Ninkovich and Heezen*, 1965; *Galanopoulos and Bacon*, 1969; *Luce*, 1969]. Recently, *Hammer et al.* [1980] have detected in a Greenland ice core a very strong acidity peak around the year 1390 ± 50 B.C., which they have related specifically to the great Thera eruption.

## OTHER ERUPTIONS

To supplement our preceding discussion of the greatest known eruptions occurring in, or reported from, the ancient Mediterranean, about which there is (as we have seen) a rather surprising amount of available information, we present a catalog of all the known ancient Mediterranean eruptions (Table 1). Too few details are known about the smaller eruptions to warrant extensive discussion, but we do supply a full set of references to them. Estimates of the eruption intensities are also provided, using the following abbreviations: VL, very large; L, large; M, medium; S, small. Uncertainties in the assigned years of these eruptions are indicated by a hyphenated range for the date or simply by ca. (Note that the hyphenated range for the years does not indicate continuing activity.) Some discrepancies exist with the years assigned in previous catalogs; one should not inadvertently infer from this that different eruptions occurred in these years.

To complement the catalog of specific eruptions, we will give below a brief summary of more general evidence concerning ancient volcanic activity in the Mediterranean. We emphasize that the surviving records are so far from complete that there is no point in listing the many miscellaneous reports of minor phenomena like solfatara fields, fumaroles, hot springs, crater lake phenomena, etc.

Chronology is often a problem. The dates of several ancient authors (or of their sources) are poorly known, and, if no specific eruption is mentioned, it is sometimes unclear whether an author is referring to activity in his own time or in some earlier time. Nevertheless, we are in a position to rule out many of the claimed "eruptions" listed in earlier catalogs. In what follows, we shall identify explicitly the most frequently mentioned of these spurious eruptions, giving the original source of error in each case. One exception will be the unpublished catalog of K. K. Hirschboeck (1976), in which the number of newly committed errors for the ancient period is so large as to render this part of the catalog of little use.

### *Aeolian Islands*

*Eighth century B.C.* Smoke and fire appeared in the Aeolian Islands (Homer, *Odyssey* 10.1–3, 12.59–72, 12.202, 12.219; cf. scholia to 10.1, 10.20; Diodorus Siculus 5.7.7; Strabo 1.2.9, 6.2.10; Eustathius, *Commentary on Homer's Odyssey* 10.1, 10.21, 12.70). It can be assumed that Homer is transferring his contemporary geographical knowledge to these accounts of the mythical (but, traditionally, thirteenth century B.C.) voyages of Odysseus and of the Argonauts (for the latter voyage, see also Apollodorus, *Library* 1.9.25, *Epitome* 7.20).

*Late sixth century B.C.* Lipari (Vulcano?) active after a 16-year quiescence (Xenophanes in pseudo-Aristotle, *On Marvellous Things Heard* 38).

*Late fifth century B.C.* Vulcano active (Thucydides 3.88).

But no specific eruption ought to be inferred from *Simkin et al.* [1981]

*Late fourth century B.C.* Fire in the Aeolian Islands and in the neighboring sea (Theophrastus in Antigonus of Carystus, *Marvels* 145; Theophrastus in scholium to Apollonius Rhodius, *Argonautica* 4.834; pseudo-Aristotle, *On the Cosmos* 395b20-23, *On Marvellous Things Heard* 37, 105).

*Early third century B.C.* Vulcano active (Callias in scholium to Apollonius Rhodius, *Argonautica* 3.41; Theocritus, *Idylls* 2.133-134). No specific eruption, though, ought to be inferred from *Simkin et al.* [1981]. Callias mentions two craters, one of which had a circumference of 3 stadia (600 m); the second one probably formed during the eruption of ca. 330 B.C. (see Table 1). Much later, in 215 B.C., the sea was reported to be on fire (around the Aeolian Islands?) (Livy 23.31.15; Zonaras 9.3).

*Mid second century B.C.* Vulcano active (Polybius in Strabo 6.2.10). Polybius reported three craters; the third was probably formed during the eruption of 183 B.C. (see Table 1). The largest crater apparently had a circumference of 5 stadia (900 m) and a height above sea level of 1 stadium (185 m).

*First century B.C.* Fire appeared on the islands of Vulcano and Stromboli and in the neighboring sea (pseudo-Scymnus, *Periegesis* 254–261; Diodorus Siculus 5.7.1–7; Strabo 5.4.9, 6.2.10–11; Varro in Servius, *Commentary on Vergil's Aeneid* 1.52; Vergil, *Aeneid* 8.416–422). Stromboli's activity is first explicitly mentioned in this century. The sudden birth of an islet near Vulcano, dated by some modern authors at 91–87 B.C. (following Pliny the Elder 2.238), probably occurred in 126 B.C. (see Table 1). On the other hand, a rain of ashes was reported to have fallen at Athens in 88 B.C. (Pausanias 9.6.6). Another supposed eruption of Vulcano, in ca. 44 B.C., was listed by *Kircher* [1678] as a result of his confusing the eruption of Etna in 44 B.C. with the nearly simultaneous eruptions of Etna and Vulcano in 126 B.C.

*First century A.D.* Vulcano and Stromboli active (Justin-Trogus 4.1; Ovid, *Metamorphoses* 14.86–87; Pomponius Mela 2.7; *Aetna* 435–448; Pliny the Elder 3.93–94; Silius Italicus 14.56–57). For a brief period, though, Vulcano was quiet.

*Mid second century A.D.* Vulcano and Stromboli active (Pausanias 10.11.4). *De Dolomieu* [1783] described an eruption of Vulcano in A.D. 144 in terms that are almost identical to those he applied to the well-known eruption in A.D. 1444. We suggest that the unspecified author who was his source made an obvious error in transcribing the date.

*A.D. 200–250.* Vulcano and Stromboli active (Philostratus, *Picture Gallery* 2.17; Solinus 6).

*A.D. 250–500.* No information is available for this period. *Alfano and Friedlaender* [1929] have wrongly inferred an eruption of Stromboli somewhere in the period A.D. 379–395 from Pacianus, who mentions only Etna and Vesuvius (see below).

*Sixth century A.D.* Vulcano and Stromboli active (Cassiodorus, *Variae* 3.47; Stephanus of Byzantium, *s.v.* Strongyle; Gregory the Great, *Dialogues* 4.30).

### *Alban Mount*

*First millenium B.C. Nissen* [1883] has described an early Alban necropolis covered by a mudflow of presumably volcanic origin.

*Circa 640 B.C.* Rain of stones at the Alban Mount—legendary (Livy 1.31.1–4, 7.28.7; Pompeius Festus, *s.v.* Novendiales; scholium to Juvenal 4.60). The date certainly cannot be as late as 540 B.C., as listed by *Sapper* [1917]. In any case, statistical evidence from Livy and Obsequens suggests that "rains of stones" were reported from central Italian territory about once every three years, on the average, before the Roman Imperial period; these "stones" cannot be volcanic in origin in most cases (they are probably large hailstones).

*257 B.C.* Rain of stones at the Alban Mount (Zonaras 8.12).

*212 B.C.* Rain of stones at the Alban Mount (Livy 25.7.7).

*113 B.C.* Alban Mount seemed to be on fire at night (Obsequens 38). Could this have been a forest fire? Probably the Alban volcano became extinct before 640 B.C.

### *Arabian Volcanoes*

Ancient historical sources make no definite mention of volcanic eruptions in Arabia, although a number of Biblical passages could have been inspired by eruptions in that region before 700 B.C. [e.g., *van Padang*, 1963]. Van Padang has also noted some possible lava flows in early medieval times that are perhaps alluded to by Arab authors writing after A.D. 630.

### *Argaeus (= Erciyas Dagi)*

In the late first century B.C., fire emerged around the base of Mount Argaeus in Cappadocia (central Turkey) (Strabo 12.2.7). Dying volcanism is sometimes thought to be the most obvious explanation since the mountain is volcanic [*Frazer*, 1914; *Wood*, 1982], but Strabo's detailed description may rather refer to burning marsh gas. Claudian (*Against Rufinus* 2.30–31, *Against Eutropius* 2.114–115) is occasionally cited on this question, but his two references seem to be only metaphors describing the effects of war. Cappadocian coins of the Roman Imperial age sometimes show Mount Argaeus surmounted by one or three stars. These stars are not representations of volcanic eruptions but rather are symbols of the local deity (Solinus 46) and perhaps also of Mithra and of the sun god [*Sydenham*, 1933].

### *Chimaera (= Yanar)*

*Fourth century B.C.* Fire emerged from a chasm atop Mount Chimaera in Lycia (southern Turkey) (Ctesias in Antigonus of Carystus, *Marvels* 182; Ctesias in Pliny the Elder 2.236; Ctesias in Photius, *Library* 72; pseudo-Scylax, *Periplus* 100; Palaephatus 28; pseudo-Aristotle, *On Marvellous Things Heard* 127).

*A.D. 1–70.* Fire burned on Mount Chimaera and on the nearby mountains of Hephaestium (Ovid, *Metamorphoses* 9.647; Seneca, *Letters* 79; Pliny the Elder 2.236, 5.100). Pomponius Mela (1.15), however, refers to "former fires."

*Third century to fourth century A.D.* Fire emerged from a chasm atop Mount Chimaera (Solinus 40; Methodius in Photius, *Library* 234; scholium to Homer, *Iliad* 15.189; Servius, *Commentary on Vergil's Aeneid* 6.288; Diodorus of Tarsus in Photius, *Library* 223). According to Methodius and Jerome (*Letters* 54), the mountain was also called Olympus. It has been identified as being near Adrasan Burnu in a nonvolcanic region (T. A. B. Spratt in work by *Smith* [1870]). Its small, unquenchable flame apparently arose from burning naphtha.

*Eifel Field*

In A.D. 58, flames shot up from the ground somewhere near Cologne (Tacitus, *Annals* 13.57). *Furneaux* [1891] interpreted this as the burning of a peat moor by spontaneous combustion. However, the Eifel region, just south of Cologne, is known to have been volcanic in prehistoric times.

*Etna*

*Fifteenth century to eleventh century B.C.* Mount Etna had violent eruptions—legendary (Diodorus Siculus 5.6.3). The uncertain date of these pre-Greek eruptions hinges on when the Sicels invaded Sicily, but it is probably closer to the eleventh century B.C. than to an earlier century (see Thucydides 6.2; Dionysius of Halicarnassus, *Roman Antiquities* 1.22). A late myth relates that the Argonauts (traditionally of the thirteenth century B.C.) saw Mount Etna in eruption (pseudo-Orpheus, *Argonautica* 1250). Myths of earlier times, for example, the stories of Typhon, Enceladus, Hephaestus, and the Cyclopes [*Huelsen*, 1894], suggest very early Greek knowledge of Etna's activity.

*Eighth century B.C.* Mount Etna active (Hesiod, *Theogony* 860; cf. Eratosthenes in Strabo 1.2.14; Tzetzes' scholium to Lycophron, *Alexandra* 688–689). But a specific date of 735 B.C. cannot be inferred (contrary to *Imbo* [1965]). Hesiod is probably describing the scanty geographical knowledge of his own time. Curiously, Homer does not mention Mount Etna.

*Circa 430 B.C.* Empedocles fell or threw himself into the fires of Mount Etna according to an ancient tradition (Strabo 6.2.8, 6.2.10; Horace, *Poetic Art* 464–466; Tatian, *Address to the Greeks* 3; Lucian, *Dialogues of the Dead* 416, *The Dead Come to Life* 2, *The Runaways* 2, *Icaromenippus* 13, *The Passing of Peregrinus* 1, 4; Tertullian, *Apology* 50, *On the Soul* 32; Diogenes Laertius 8.69–75; Lactantius, *Divine Institutes* 3.18; Gregory of Nazianzus, *Epigrams* 28, *Poem to Nemesius* 281–284, *Epitaphs* 69; Claudian, *Panegyric on the Consulship of Manlius* 72; Sozomen, *Ecclesiastical History* 2.24; Hermias, *Derision of the Pagan Philosophers* 8; *Greek Anthology* 7.123, 7.124, 8.28; *Suda*, *s.vv.* Amyclae, Empedocles). No actual eruption is implied, and a date of 565 B.C. [*Imbo*, 1965] is incorrect.

*Circa 387 B.C.* Plato seems to have witnessed a lava flow of Mount Etna (Plato, *Phaedo* 111E; Apuleius, *On Plato* 1.4; Athenaeus 11.507; Diogenes Laertius 3.18; Sozomen, *Ecclesiastical History* 2.24; Olympiodorus, *Life of Plato*).

*Late fourth century B.C.* Etna active (Theophrastus in Diogenes Laertius 5.49; pseudo-Aristotle, *On the Cosmos* 395b20–23, *On Marvellous Things Heard* 38, 40, 105).

*First century B.C.* Etna active (Posidonius in Strabo 6.2.3; Lucretius 1.722–725, 6.680–702; Diodorus Siculus 4.21.5, 5.7.3–4; Strabo 5.4.9, 6.2.8–10). According to Strabo, the circumference of the summit crater was 20 stadia (3700 m). Specific eruption dates of 61, 56, and 10 B.C. given by *Imbo* [1965] cannot be supported from the ancient reports.

*First century A.D.* Etna active at times (Justin-Trogus 4.1; Ovid, *Metamorphoses* 15.340–355; Pomponius Mela 2.7; Seneca, *Letters* 51, 79; *Aetna*, *passim*; *Aetna* in Servius, *Commentary on Vergil's Aeneid* 3.571; Pliny the Elder 2.236, 3.88; Valerius Flaccus 2.30–32; Silius Italicus 14.58–69; Apollodorus, *Library* 1.6.3; Philostratus, *Life of Apollonius* 5.14–17; Philostratus in Photius, *Library* 241; Longinus, *On the Sublime* 35.4). Around the middle of the century, Etna was apparently relatively quiet (Seneca, *Letters* 79). *Sartorius von Waltershausen* [1880], however, has greatly exaggerated a stock description of Mount Etna provided by Pomponius Mela in order to suggest an eruption in ca. A.D. 50. He and Bunbury [*Smith*, 1870] have also suggested another eruption in A.D. 70–72, purportedly described in the *Chronicle* of Hydatius. This eruption, however, is spurious; it results from accidentally combining two unrelated passages dealing with the second year of Vespasian's reign (A.D. 70) and an eruption of Etna in 425 B.C., which appear juxtaposed in the *Chronicle* of Jerome (Olymp. 88), the immediate predecessor of Hydatius' *Chronicle*.

*Second century A.D.* Etna active at times (Florus, *Epitome* 1.11; Pausanias 3.23.9; Hyginus, *Fables* 152). The volcano was undoubtedly quiet in A.D. 125, when Hadrian ascended it (*Augustan History*, *Hadrian* 13.3). There is no justification for assigning a particular eruption to A.D. 165 (contrary to *Sartorius von Waltershausen* [1880]).

*Third century A.D.* Etna active (Minucius Felix 35; Solinus 5, 40; *Acts of Pionius* 5, February 1, Bollandists; *Acts of Patricius* 1, April 28, Bollandists). Solinus mentions two summit craters.

*Fourth century A.D.* Etna active (*Geographical Description of the World* 65, Mueller; Quintus Smyrnaeus 14.584–585; *Acts of Philip* 8, May 12, Bollandists; Servius, *Commentary on Vergil's Aeneid* 3.573; Pacianus, *Exhortation to Penitence*, Migne, *PL*, *13*, 1088–1089; Claudian, *Rape of Proserpine* 1.153–178; Diodorus of Tarsus in Photius, *Library* 223). Pacianus (writing in A.D. 379–395) does not report a specific eruption (contrary to *Alfano and Friedlaender* [1929]).

*Early fifth century A.D.* Etna active at times (Orosius 2.14; Olympiodorus in Photius, *Library* 80; Augustine, *City of God* 21.4; Salvian, *On the Governance of God* 7.16). In the first two decades of this century, Etna was comparatively quiet, according to Orosius and Olympiodorus. *Sartorius von Waltershausen* [1880] has wrongly claimed an eruption in ca. A.D. 420 on the basis of Solinus' (third century A.D.) description of Etna. *Imbo*'s [1965] eruption dates of A.D. 400 and 410 can be discounted.

*Mid sixth century A.D.* Etna active (Procopius, *Wars* 8.35.5). Procopius does not mention specific eruptions in the period A.D. 500–560 (contrary to *Sartorius von Waltershausen* [1880] and *Imbo* [1965]).

*A.D. 604.* The year given for this supposed eruption of Etna [*Imbo*, 1965] appears to be only a reference number to a text of Gregory the Great cited by *Sartorius von Waltershausen* [1880].

*Euboea*

At an unspecified date before the first century A.D., the Lelantine Plain on the island of Euboea, Greece, apparently erupted hot mud or lava (Strabo 1.3.16). Possibly the date was 199–197 B.C. (cf. Justin-Trogus 30.4). Hot sulfur springs are still active on the island.

*Ischia*

*Fourth century B.C.* Ischia had become less active after a long period of vigorous volcanism (pseudo-Aristotle, *On Marvellous Things Heard* 37). Knowledge of the island's volcanic activity goes back, apparently, to the age of the earliest mythographers (Pherecydes in scholium to Apollonius Rhodius, *Argonautica* 2.1211; Pindar, *Pythian Odes* 1.18;

TABLE 1. Catalog of Historically Recorded Eruptions of Mediterranean Volcanoes to A.D. 630

| Year | Month/Day | Volcano | Intensity | References and Notes |
|---|---|---|---|---|
| B.C. 1500–1400 | | Thera | VL | See main text. |
| 696–693 (or 456–453) | | Etna | L | Thucydides 3.116; Ctesias in Photius, *Library* 72; Lycurgus, *Against Leocrates* 95–96; pseudo-Aristotle, *On the Cosmos* 400a 33–b6, *On Marvellous Things Heard* 154; Diodorus Siculus 20.101.3; Strabo 6.2.3; Conon (*Narratives* 43) in Photius, *Library* 186; Valerius Maximus 5.4; Seneca, *On Benefits* 3.37.2, 6.36.1; *Aetna* 606–646; Silius Italicus 14.196–197; Pausanias 10.28.4; Hyginus, *Fables* 254; Aelian in Stobaeus, *Florilegium* 79.38; Philostratus, *Life of Apollonius* 5.17; Solinus 5; Julius Paris, *Epitome of Valerius Maximus* 5.4; Claudian, *Minor Poems* 17. Lava reached, or nearly reached, Catania. Depictions on monuments are described by *Alessi* [1829]. On the date, see *Bergk* [1873]. |
| ca. 500 | | Ischia | | Strabo 5.4.9. The island experienced earthquakes. |
| 479–475 | winter? | Etna | L | Pindar, *Pythian Odes* 1.19–28; Aeschylus, *Prometheus Bound* 365–374; Thucydides 3.116; *Parian Marble*, epoch 52; Callimachus in scholium to Aeschylus 368; Favorinus in Aulus Gellius 17.10; [Favorinus in] Macrobius, *Saturnalia* 5.17. Lava may have flowed to the sea. On the date, see *Bergk* [1873]. |
| ca. 470 | | Ischia | | Pindar, *Pythian Odes* 1.18; Strabo 5.4.9 |
| 425 | spring | Etna | L | Thucydides 3.116; Julius Africanus in George Syncellus, *Chronography*, Olymp. 88; Eusebius-Jerome, *Chronicle*, Olymp. 88; Orosius, *Against the Pagans* 2.18. Lava flowed in the direction of Catania. Sicily experienced an earthquake. |
| 396 | summer? | Etna | L | Diodorus Siculus 14.59.3. Lava flowed to the sea northeast of Catania. |
| ca. 350 | | Ischia | M | Timaeus in Strabo 5.4.9; *Aetna* 430; Pliny the Elder 2.203. The main peak, Epomeo, erupted. Earthquakes and a tsunami struck the island. |
| ca. 330 | | Vulcano | L | Aristotle, *Meteorologica* 367a2–9; Callias in scholium to Apollonius Rhodius, *Argonautica* 3.41. The earth bulged and broke; ashes went as far as Lipari and the Italian mainland. |
| 276–239 | | Methana | L | Strabo 1.3.18; Ovid, *Metamorphoses* 15.296–306; Pausanias 2.34.1. The earth bulged to a height of 7 stadia (1300 m) and broke; lava flowed. On the exact location in the Saronic gulf, see *Meyer* [1932]; the volcano is probably Kameno Vouno (now 760 m in elevation). |
| 269 | | Roccamonfina? | S | Orosius 4.4. A flame shot up and burned for three days near Cales. |
| 217–216 | summer? | Vesuvius? | VL? | See main text. |
| 199–197 | | Thera | M | Posidonius and Asclepiodotus in Seneca, *Natural Questions* 2.26.4–7; Strabo 1.3.16; Justin-Trogus 30.4; Pliny the Elder 2.202, 4.70; Plutarch, *On the Pythian Responses* 399C; Pausanias 8.33; Eusebius-Jerome, Olymp. 145; Ammianus Marcellinus 17.7.13. A new island, Hiera, formed midway between Thera and Therasia in 4 days and had a circumference of 12 stadia (2200 m). Earthquakes occurred in Rhodes and elsewhere in the eastern Mediterranean. On Pliny's (2.202) probably mistaken date, see, for example, *Smith* [1870] under "Thera." |
| 183 | | Vulcano | M | Livy 39.56.6; Pliny the Elder 2.203; Ammianus Marcellinus 17.7.13; Obsequens 4; Orosius 4.20; Cassiodorus, *Variae* 3.47. A new island (Vulcanello?) arose near Vulcano. |
| 141 | | Etna | | Obsequens 23 |
| 135 | | Etna | L | Lucan 1.43; Obsequens 26; Orosius 5.6. Lava and ashes were erupted. |
| 126 | before June? | Etna | L | Obsequens 29; Orosius 5.10. The summit erupted, and an earthquake occurred. |

TABLE 1. (continued)

| Year | Month/Day | Volcano | Intensity | References and Notes |
|---|---|---|---|---|
| 126 | June | Vulcano | M | Posidonius in Strabo 6.2.11; Pliny the Elder 2.203, 2.238; Eusebius-Jerome, Olymp. 163; Obsequens 29; Orosius 5.10. A new island arose between Vulcano and Panaria and caused a tsunami. On the location and on Pliny's (2.238) and Strabo's misleading dates, see, for example, Bunbury in the work by *Smith* [1870] under "Aeoliae Insulae." |
| 122–121 | | Etna | L | Lucretius 6.639–646; Obsequens 32; Orosius 5.13; Augustine, *City of God* 3.31. Possibly also Cicero, *On the Nature of the Gods* 2.96; Seneca, *Natural Questions* 2.30.1; Hermogenes, *On Invention* 2.2, 3.12. Lava flowed from the summit to the sea; ashes partly buried Catania. |
| 104 | | Vulsini | S | Obsequens 43. A flame shot up near Volsinii. |
| 91 | | Ischia, Roccamonfina, or Vulsini | S | Pliny the Elder 2.199; Obsequens 54; Orosius 5.18. A flame shot up from the ground, with an earthquake. Aenaria (Ischia), Aesernia (Samnium), Aemilia (Modena), and Oenaria (Etruria) are possible locations; *Oudendorp* [1720] favors Aesernia. The Modena area, it seems, is generally nonvolcanic (but see Pliny the Elder 2.240). |
| 50–49 | | Etna | | Lucan 1.545–548; Petronius, *Satyricon* 122.135–136. Hot ash or lava flowed toward Italy. |
| 44 | March? | Etna | VL | See main text. |
| 36 | summer | Etna | | Appian, *Civil Wars* 5.117 |
| 32 | | Etna | | Dio, *Roman History* 50.8.3 |
| A.D. 38–40 | | Etna | | Suetonius, *Caligula* 51. Possibly this was not a true eruption. |
| 46 | | Thera | | Seneca, *Natural Questions* 2.26.6, 6.21.1; Pliny the Elder 2.202, 4.70; Dio 60.29.7; Philostratus, *Life of Apollonius* 4.34; Eusebius-Jerome, Olymp. 206; Aurelius Victor, *Caesars* 4; *Epitome of Caesars* 4; Orosius 7.6; Cassiodorus, *Chronicle*, Mommsen, *MGH*, *11*, 137. A new island, Thia, arose between Thera and Therasia. 2 stadia (400 m) from Hiera, and had a dimension (circumference?) of about 30 stadia (5600 m). An earthquake and a tsunami struck Crete. On Pliny's (2.202) probably mistaken date, see, for example, *Smith* [1870] under "Thera"; *Oltramare* [1929] states the particular day as December 31 (on the basis of Aurelius Victor's report of a concurrent lunar eclipse?). |
| 79 | August 24–25? | Vesuvius | VL | See main text. |
| 202–203 | | Vesuvius | | Dio 76.2.1–2 |
| 252 | February 1–5 | Etna | L | Isidore of Seville, *Hymns* 1, 2; Aldhelm, *On the Praise of Virgins* 32; Methodius the Confessor, *Oration on Agatha* 30–33; Petrus Thaumaturgus, *Oration on Athanasius* 3; Symeon Metaphrastes, *Life of Agatha* 18; *Acts of Agatha* (Latin) 15; *Acts of Agatha* (Greek) 14. These references can be found in the *Acts of Agatha*, February 5, Bollandists. This was a flank eruption, with earthquakes. Lava very nearly reached Catania. |
| 417–425 | | Etna | | Olympiodorus in Photius, *Library* 80 |
| 469–474 | before Nov. 6 | Vesuvius | VL | See main text. |
| 505 | November 9 | Vesuvius | | *Paschale Campanum*, Mommsen, *MGH*, *9*, 747 |
| 512 | July 8 | Vesuvius | L | Cassiodorus, *Variae* 4.50; *Paschale Campanum*, Mommsen, *MGH*, *9*, 747. Procopius (*Wars* 8.35.5–6) describes a great lava flow before A.D. 536. Possibly Cassiodorus, who seems to mention only historic ash flows, is describing the A.D. 505 eruption. |
| 536 | before March 24 | ? | VL | See main text. This was probably not a Mediterranean eruption. |
| 626 | October | ? | VL | See main text. Possibly this was not a Mediterranean eruption. |

Lycophron, *Alexandra* 688–690; Strabo 5.4.9, 13.4.6; Lucan 5.100–101; Silius Italicus 8.540–541; Servius, *Commentary on Vergil's Aeneid* 9.712).

*First century to fourth century A.D.* Ischia had become effectively extinct by the first century A.D. (*Aetna* 431). *Fazello* [1558], however, has listed, without giving sources, four eruptions of the main peak (Epomeo) during the reigns of Augustus (27 B.C. to A.D. 14), Titus (A.D. 79–81), the "fourth" Antoninus (one of the emperors between A.D. 180 and 222), and Diocletian (A.D. 285–305). (*Chevalley de Rivaz* [1859] incorrectly took Fazello's Antoninus to be the first Antoninus, A.D. 138–161.) Fazello must have inferred these four "eruptions" from references to related phenomena, like hot springs and earthquakes, by contemporary authors, for example, Strabo (5.4.9) in the first case and Valerius Flaccus (3.208–209) in the second. Fazello's sources for the last two eruptions have never been identified.

### *North Turkey*

Circa 330 B.C. there was an eruption of "wind" from the ground near Heraclea in Pontus (Aristotle, *Meteorologica* 366b31–367a1). This was probably only an earthquake, for the region has not been volcanically active since the Tertiary period.

### *Thera (= Santorini)*

For the third century B.C. to the first century A.D., Pliny the Elder's (2.202) text implies three eruptions of Thera: 237 B.C., 107 B.C., and A.D. 3 (or A.D. 19). The abundant testimony of other ancient authors, however, indicates only two eruptions and points overwhelmingly to the years ca. 197 B.C. and A.D. 46 (see Table 1). *Smith* [1870] nevertheless regards Pliny's total number of eruptions as correct and infers 67 B.C. for the date of the third eruption.

### *Vesuvius*

*Eighth century B.C. Alfano and Friedlaender* [1929] mention a prehistoric, pumice-filled necropolis of this date at Sarno, to the south of Mount Vesuvius. The myth that Heracles and the gods battled the Giants on the Phlegraean Fields and thrust one of them, Alcyoneus, under Mount Vesuvius (Diodorus Siculus 4.21.5; Dio 66.22.2, 66.23.1; Philostratus, *Heroica* 1.4; Claudian, *Rape of Proserpine* 3.184–185) (while other Giants were thrust under Mount Etna and Mount Epomeo) perhaps preserves a dim memory of prehistoric activity of this mountain. A twelfth century B.C. date [*Imbo*, 1965] is only a guess.

*611 B.C.* Possibly an eruption of Vesuvius caused the rain of "pitch" that was reported to have fallen on North Africa between Tripoli and Cyrene in this year (Pliny the Elder 19.41) if the almost identical range of fallout after the famous eruption of A.D. 79 can be used as a valid analogy. An early eruption of Vesuvius might also explain Xenophanes' (sixth century B.C.) story of a solar eclipse that lasted a whole month (Aëtius, *Opinions* 2.24). However, these phenomena do not necessarily refer to an eruption of Vesuvius.

*A.D. 80–120.* Continuing mild activity of Mount Vesuvius after the great eruption of A.D. 79 (Martial, *Epigrams* 4.44; Statius, *Silvae* 4.4.79–85; Tacitus, *Annals* 4.67; Florus, *Epitome* 1.11).

*A.D. 170–220.* Continuing mild activity of Mount Vesuvius, with a smoke plume by day and a glow at night (Galen, *On the Healing Art* 5.12; Tertullian, *On Penitence* 12; Minucius Felix 35; Dio 66.21–22; Philostratus, *Heroica* 1.4; Solinus 2, 40). Galen makes no specific mention of an eruption in A.D. 172 (contrary to *Alfano and Friedlaender* [1929]) or ca. A.D. 203 (contrary to *Phillips* [1869]), although Dio records one in the latter year (see Table 1).

*A.D. 220–350.* No definite information about Mount Vesuvius exists for this period. The "eruptions" of A.D. 222–235 (Bunbury in the work by *Smith* [1870]; also *Alfano and Friedlaender* [1929]) are clear exaggerations of what Dio (66.21–22) actually wrote (and wrote before A.D. 229). The source for an "eruption" in A.D. 243 [*Mecatti*, 1752] has never been identified. Another eruption, falsely attributed to the lifetime of St. Januarius and dated A.D. 305 [*Majoli*, 1615], actually occurred much later, possibly in A.D. 685 (*Acts of Januarius*, September 19, Bollandists). The "eruption" of A.D. 321 is a consequence of two errors: first, a false attribution by *Mecatti* [1752] to the time of Constantine I and to Mount Vesuvius, in particular, of very general volcanic phenomena mentioned in a Sibylline prophecy which is quoted in Constantine I's *Oration* (18), and, second, a wrong assignment of the "eruption of the 16th year of Constantine IV" [*Capaccio*, 1771] to the corresponding year of Constantine I.

*Late fourth century A.D.* Continuing mild activity of Mount Vesuvius (Ausonius, *Moselle* 210; Pacianus, *Exhortation to Penitence*, Migne, *PL*, *13*, 1088–1089; *Epitome of Caesars* 10; Diodorus of Tarsus in Photius, *Library* 223). Pacianus (writing in A.D. 379–395) does not report a specific eruption during this period (contrary to *Alfano and Friedlaender* [1929]).

*Fifth century to sixth century A.D.* The claimed "eruptions" of A.D. 454 and 557 [*Mecatti*, 1752] are easily traced to errors in the dates, which should read A.D. 474 and 536. But it ought to be pointed out that the latter "eruption" has been inferred only from the mountain's premonitory rumblings in that year (Procopius, *Wars* 6.4.21–28). Jordanes' (ca. A.D. 550) (*Roman History* 143) reference to Vesuvius is only a stock description of the volcano.

### *Vulsini*

Circa 500 B.C., "lightning" destroyed the town of Volsinii—legendary (Pliny the Elder 2.139–140; Tertullian, *To the Nations* 1.9, *Apology* 40, *On the Pallium* 2). Could this have been a volcanic eruption? Vulsini was not yet extinct (see Table 1).

### *West Africa*

In the fifth century B.C. an isolated mountain of West Africa called the "Chariot of the Gods" was seen to be on fire (Hanno, *Periplus*; see also pseudo-Aristotle, *On Marvellous Things Heard* 37; Diodorus Siculus 3.53.6; Pomponius Mela 3.9; Pliny the Elder 2.238, 6.197; Arrian, *Indica* 43). This mountain has been variously taken to be one of the Atlas Mountains, or Mount Kakulima, or Mount Cameroon, among other possibilities [*Cary and Warmington*, 1929; *Carcopino*, 1944]. The various explanations of the fire have ranged from blazing grass fires to a volcanic eruption. The volcanic interpretation would fit only Mount Cameroon.

## NO EVIDENCE IN EUROPE OF THE TAUPO ERUPTION

Recently, *Wilson et al.* [1980, 1981] claim to have found literary evidence that the great Taupo eruption in New Zealand (radiocarbon dated at about A.D. 130) occurred in,

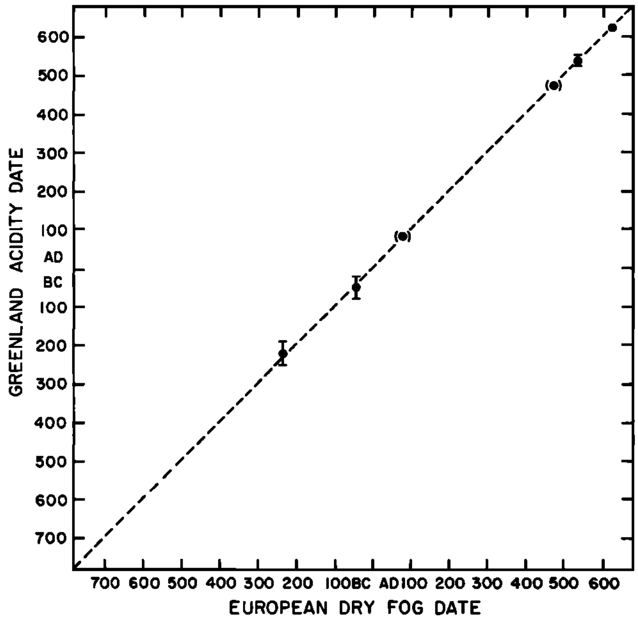


Fig. 1. Correlation between two independent indicators of large explosive volcanic eruptions, 735 B.C. to A.D. 630. These indicators are European historical dry fogs and the largest Greenland ice core acidity peaks. Two known large Mediterranean eruptions during the period A.D. 44–540, not covered by the available ice cores, are shown in parentheses along the 45° line.

or just before, A.D. 186. They cite in their favor two ancient Western sources and one ancient Chinese source. Only the Western sources concern us here. Herodian (*Roman History* 1.14.1) and, much less importantly, the *Augustan History* (*Commodus* 16.2) contain descriptions of unusual appearances of the sky during the reign of the Roman emperor Commodus (A.D. 180–192). Unfortunately, Wilson et al. have adopted an old English version (not identified) of the passage from Herodian in which the key word heteroi was mistranslated and a long gloss beginning "which was a token . . . " was added by the translator. A correct and full modern translation is given here: "Some stars shone continuously by day, others become elongated and seemed to hang in the middle of the sky" [*Whittaker*, 1969]. Since Herodian establishes a strong antithesis between hemerioi ("by day") and heteroi ("others"), the supposed evidence for elongated haze seen at dawn and dusk (i.e., in the daytime) disappears. A critical discussion of the available literary sources has already shown that the two passages in question probably refer either to the supernova of A.D. 185 or else to the bright comets and aurorae of the period A.D. 182–192 [*Stothers*, 1977]. Objections of a purely geological nature to the idea of a Taupo influence in Europe have also been raised by *Froggatt* [1981], essentially on the grounds that the volcano lies too far south (39°S). Counterarguments, however, have been given by *Wilson et al.* [1981].

## CONCLUSIONS

The most important result of the present study, in our opinion, is the final availability of a reliable catalog of historically recorded volcanic eruptions and their associated effects, reported from the Mediterranean region before A.D. 630. In compiling this catalog from the original sources, we have been able to correct the errors and omissions of earlier catalogs and to increase by many times the number of ancient references now available for scientific scrutiny. Eruptions have been identified in the usual manner by direct reports of eruption columns, ash and pumice falls, nuées ardentes, lava flows, and volcanic cone alterations. But we have also introduced indirect evidence of a less familiar kind for the very largest (sometimes distant) eruptions, including dimming of the sun, atmospheric haze, solar haloes, and glowing skies as well as unusual earthquake activity, remote ash falls, atmospheric temperature decreases, and crop failures. No reports of unusually dark total lunar eclipses were encountered, however.

The eruption chronology is probably very nearly complete for those few events that had widespread geologic and atmospheric effects. There are at least seven of these events: Thera (fifteenth century B.C.), Vesuvius or some other northern hemisphere volcano (217 B.C.), Etna or some other northern hemisphere volcano (44 B.C.), Vesuvius (A.D. 79 and A.D. 472), and two northern hemisphere volcanoes (A.D. 536 and A.D. 626). The fifteenth century B.C. eruption of Thera has been discussed in detail by many authors. The 217 B.C. eruption of Vesuvius has not to our knowledge been noted before in the geologic literature; if real, it was the earliest historical eruption of the world's most famous volcano, although it need not have caused the dry fog of that year. The similarities among the ancient reports of this eruption, the one in A.D. 472, and the well-known A.D. 79 eruption support the conclusion that they were all large plinian events. The 44 B.C. eruption of Etna also seems to have been a large explosive event with widespread geologic effects and perhaps caused that year's dry fog. Similarly, major explosive events occurring somewhere in the northern hemisphere (north of 20°S) in A.D. 536 and A.D. 626 were undoubtedly the source of the atmospheric disturbances in those years. Probably a distant volcano (Rabaul, New Britain?) was responsible for the unparalleled atmospheric disturbance in A.D. 536.

Since the persistence of atmospheric veiling may provide a rough measure of the explosive magnitude of a volcanic eruption [*Lamb*, 1970], it is interesting to find that the eruptions of 44 B.C., A.D. 472, A.D. 536, and A.D. 626 produced approximately 9, 12, 18, and 9 months of veiling, respectively. There seems to have been associated with the veiling a protracted period of unusually cold weather, which drastically affected crop yields in those years. Unfortunately, the duration of the dry fog in 217 B.C. is unknown, and information concerning possible dry fogs in the fifteenth century B.C. and in A.D. 79 is lacking. In any case, similar consequences of very large explosive eruptions have been felt in Europe in modern times.

Another indication that these eruptions had widespread atmospheric effects comes from the presence in Greenland ice cores of marked acidity peaks around the years 260 ± 30 B.C., 210 ± 30 B.C., 50 ± 30 B.C., A.D. 540 ± 10, and A.D. 623 ± 3 [*Hammer et al.*, 1980]. These peaks are almost certainly volcanic in origin. Within the time intervals where our European dry fog data and the present Greenland ice core data overlap, there is a nearly perfect one-to-one correspondence (except for 260 B.C.) between these two independent tabulations of major volcanic years, as shown in Figure 1. A gap exists in the detailed ice core record between A.D. 44 and roughly A.D. 540; from our work, we predict that if and when detailed ice core data become available for this interval, peaks of acidity will be found in the layers corresponding to the years A.D. 79 and A.D. 472.

The one unidentified ice core signal at 260 ± 30 B.C. belongs to a very poorly documented period in history. Nevertheless, we point out that an exceptionally cold winter was registered at Rome in 270/269 B.C. (Augustine, *City of God* 3.17; Zonaras 8.6) and that the volcano at Methana, Greece, erupted between 276 and 239 B.C. (although the magnitude of the eruption is not known well). However, radiocarbon dating has revealed a number of other major volcanic eruptions in other parts of the world during this period [*Simkin et al.*, 1981].

We believe that our new and comprehensive study has demonstrated, much more forcefully than before, the usefulness of ancient historical records for determining the character of explosive volcanic eruptions in early historical times. A similar study of ancient Far Eastern literature would be most worthwhile for establishing the hemispheric effects of these eruptions and would possibly reveal evidence for explosive volcanic events unrecorded in the extant literature of the Mediterranean civilizations.

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# Dark lunar eclipses in classical antiquity

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**Credible reports of dark lunar eclipses do not appear to exist in surviving ancient European and Near Eastern literature, apart from some undatable allusions in astrological writings.**

## A question

Two independent studies have recently given conflicting answers to the question: do reliable reports of dark total eclipses of the Moon exist in ancient European and Near Eastern literature? Authentic eclipse reports would be scientifically valuable because dark lunar eclipses have been linked both to an excess opacity in the Earth's atmosphere and to a lull in the Sun's surface activity[1]. On the one hand, Stothers and Rampino[2] state that they find no credible reports up to the seventh century AD, whereas Bicknell[3] claims a succession of dark lunar eclipses in the second and first centuries BC. Here I shall attempt to show why the ancient lunar eclipse reports cited by Bicknell cannot be unambiguously interpreted as evidence for *dark* lunar eclipses.

## Aglaonice

Plutarch, a knowledgeable Greco-Roman antiquarian who was writing *circa* AD 100, recorded that an astronomically-trained sorceress from Thessaly, named Aglaonice, used to deceive other women by pretending to 'draw down' the Moon during a lunar eclipse[4]. Bicknell[3] inferred from the presence of an audience to this exercise that the Moon's disc disappeared completely during the eclipse. The key word used by Plutarch (more properly, by his unknown source) was *kathairein*, for which the literal, popular meaning was 'draw down', but whose technical meaning would actually depend critically on the date of Aglaonice's life. Bicknell assigned this rather arbitrarily to the first century BC on the assumption that she belonged to the Greco-Roman scientific period.

Four arguments suggest rather strongly that Aglaonice was actually a mythological (or early legendary) character. First, the three other named sorceresses from classical antiquity who could 'draw down' the Moon were unquestionably mythological figures: Mycale, Medea, and Circe[5]. Secondly, the ancient attribution of a proverb 'She draws down the Moon' to an incident in Aglaonice's life[6] also suggests a very early origin for her. Thirdly, as the only named Thessalian witch other than Mycale, Aglaonice may have been the model for the numerous Thessalian bewitchers of the Moon that appeared as stock characters in Greek literature at least as early as the fifth century BC[7]. Fourthly, like the mythical Endymion, a mythical Aglaonice would have been easily endowed with 'astronomical knowledge' by the ancient rationalisers of the Greek myths (for the rationalised myth of Endymion and the Moon, see reference 8).

If Aglaonice did in fact predate the fifth century BC, as seems very likely, the word *kathairein* (in the context of eclipses) probably meant simply 'to darken'[9]. An anonymous ancient writer[10] informs us that, up to the time of Democritus (fifth century BC), *kathairein* was commonly applied to eclipses of all kinds. Since few total solar eclipses could have been seen from the small area of the Greek lands, *kathairein* must have been used generally for solar and lunar eclipses of all magnitudes. Thus, there is no reason to infer the occurrence of a *dark* lunar eclipse from Plutarch's use of the word.

## Lucretius

The Roman scientific poet Lucretius, writing *circa* 55 BC, referred in a curious way to lunar eclipses as *latebras lunae* ('hiding-places of the Moon')[11]. Bicknell[3] interpreted this odd expression as implying a succession of *dark* lunar eclipses during Lucretius' lifetime, in the mistaken belief that the term is unique in Latin literature.

Since the purpose of Lucretius' poem was to expound Epicurean theory, the origin of the term *latebras* probably lies in Epicurean scientific usage. According to a gloss in the text of Diogenes Laertius (third century AD)[12], the Greek philosopher Epicurus himself (*circa* 300 BC) used the Greek word *anachōrēsin* ('a retreat') for a lunar eclipse. A century earlier, the Greek sophist Antiphon appears to have described the New Moon as *apokryptomenon* ('hiding itself')[13]. But the figure of speech is not unique even in Latin literature. Both Pliny the Elder[14] (*circa* AD 77) and Ammianus Marcellinus[15] (fourth century AD) used *latet* ('lies hid') in general prose scientific explanations of lunar eclipses.

There are further reasons for not reading anything unusual into Lucretius' *latebras lunae.* This phrase also expressed Lucretius' abundant interest in verbal imagery and alliteration. In an important variation, Lucretius referred to lunar eclipses with the word *languescere* ('become weak')[16]. It is ironical that the historian Tacitus[17] (first century AD) used *languescere* to characterize the lunar eclipse of AD 14 September 27, which Bicknell[3] pointed to expressly as a case of an *ordinary* lunar eclipse! Both the orator Cicero, who was Lucretius' friend and posthumous editor, and the poet Vergil, a much younger contemporary, modeled the brief descriptions of lunar eclipses in their own poems after Lucretius, but saw nothing so scientifically significant in *latebras lunae* that they felt obliged to retain the term[18].

## Cicero

In an autobiographical poem, which mentioned in passing the lunar eclipse of 63 BC May 3, Cicero wrote: "the Moon at her full withdrew her bright features and was blotted out"[18]. Bicknell[3] inferred from Cicero's choice of words that the Moon completely vanished. But is this not just Ciceronian rhetoric? A poem by the satirist Petronius (first century AD) portrayed the lunar eclipse of 48 BC July 15 in a very similar way: "the Moon extinguished her full face and took away her light"[19]. In contrast, Petronius' contemporary, the poet Lucan laconically described the same eclipse of 48 BC as "the Moon became pale"[20]. It is therefore unrealistic to ascribe any significance to the reported magnitudes of these eclipses. This conclusion is reinforced by recognising in all of these poems the obvious and intentional parallels with Lucretius' poem.

In a subsequent prose passage, Cicero used the word *obscurari* ('to be darkened') to explain very generally the character of total lunar eclipses[21]. Bicknell[3] again read into Cicero the idea of complete invisibility of the Moon. Yet Pliny the Elder[22] used the same word to explain the same general phenomenon, and some other authors introduced an even stronger word, *nigris* ('black')[23].

## Lunar eclipse of 168 BC June 21

In a remarkable description of the lunar eclipse of 168 BC June 21, Plutarch wrote: "the Moon was full and high in the sky when it suddenly grew black, lost its light, changed colours of all sorts, and vanished"[24]. Plutarch's source is unknown but may have been the Roman scientist Sulpicius Gallus[25] or the historian Polybius[26], both of whom witnessed the eclipse and wrote about it in works now lost. Bicknell[3,26] claimed in this description a strong case for a *dark* lunar eclipse.

The physical details, however, appear to have been made up by Plutarch. For one thing, no other extant account of this eclipse mentions them (see especially the works cited in reference 27). In addition, Plutarch employed identical language about a sudden loss of light and a change of colours in describing the lunar eclipse of 413 BC August 27, although he did not mention any blackening and vanishing of the Moon in the latter case[28]. Yet Plutarch did know and did indicate the time of night for the 168 BC eclipse, placing it in the hours shortly after suppertime, which Livy identified more precisely as the second to the fourth hour of the night. According to pre-Greek Chaldean astrological lore, expounded by Plutarch himself[29], a lunar eclipse that occurred between eventide and a half past the third hour of the night was always supposed to be 'terribly black'. Other ancient writers bear witness to the traditional astrological significance of the various lunar eclipse colours, including the colour black[30]. Furthermore, the strong association of these colours with certain set times is independently attested by a Mesopotamian clay tablet cited by Bouché-Leclercq[31]. It is therefore very likely that Plutarch was simply drawing upon his ample astrological knowledge to infer the black colour of the 168 BC eclipse, for which he knew the hour of occurrence.

## Conclusion

It is obvious that ancient Greek and Roman authors had to invent, and then make use of, certain technical terms to describe the obscuration of the Moon during total lunar eclipses. A literal reading of these terms might lead one to suppose that *dark* lunar eclipses were a very common, if not the usual, experience over a period of more than six centuries. In so reading these words in selected ancient authors, Bicknell[3] deduced a succession of dark lunar eclipses during the second

and first centuries BC. He was, however, unable to find a plausible explanation for the large number of dark eclipses. I believe that no explanation is needed, because the technical terms have evidently been overinterpreted, and dark lunar eclipses were as rare in antiquity as they are today.

Nevertheless, some dark lunar eclipses must have occurred from time to time. The only reliable literary evidence that we possess, however, consists of a small number of undatable astrological fragments that preserve a corrupt tradition of pre-Greek Chaldean observations of dark lunar eclipses reported from Mesopotamia[32].

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# VOLCANIC WINTERS[1]

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## INTRODUCTION: THE VOLCANO/CLIMATE CONNECTION

Accounts of prolonged darkness, often associated with abnormally cold weather and hardship, are common in the myths and legends of many cultures. Egyptian papyruses corroborate the statement in the Book of Exodus in the Bible that "there was a thick darkness in all the land of Egypt for three days." Similar kinds of stories can be found in ancient Sumerian, Greek, and Mayan literature. These have on occasion been used to argue for global catastrophes, such as encounters or collisions with comets, in early historical times. A more reasonable explanation comes from the similarity of these reports to more recent historical accounts of the aftereffects of large volcanic eruptions. Thus, a substantial case has been made for the connection of the Egyptian and Biblical reports of darkness and ash rains at the time of the Exodus with the explosive

eruption of Santorini (Thera) in the Aegean Sea in the second millenium BC (see references in Downey & Tarling 1984, Stanley & Sheng 1986), which also somehow contributed to the demise of Minoan Crete (Marinatos 1939) and had effects as far away as China (Pang & Chou 1985). In more recent times, the inhabitants of interior New Guinea speak of the "time of darkness," a tradition passed down over generations since the seventeenth century AD. Blong (1982) has shown that this darkness was accompanied by large local temperature changes, both hot and cold, and was most likely related to the ash cloud from an eruption of Long Island, one of the active volcanoes off the northeast coast of New Guinea.

Considering the knowledge that we have gained in the past few decades about the mechanisms of volcanic eruptions and the generation of volcanic aerosol clouds in the atmosphere, it is reasonable to ask what the atmospheric effects of the largest eruptions might be. Beyond the local devastation and regional effects, it is known that some historical eruptions had a noticeable impact on climate and agriculture on a hemispheric to global basis. This being the case, much larger eruptions may possibly have caused severe "volcanic winters," perhaps similar to the recently proposed "nuclear winter." These "supereruptions" must therefore be considered in discussions of natural hazards that might have global consequences (Rampino et al 1985, Burke & Francis 1985, Smith 1985).

Modern interest in the problem of the impact of volcanic eruptions on the atmosphere and climate is traditionally traced back to the observations of Benjamin Franklin at the time of the eruption of Laki (Lakagígar) in Iceland in 1783. Franklin (see Lamb 1970, p. 433) described what he termed a "dry fog" in Europe during his stay there as minister to France. As Franklin wrote, the rays of the Sun "were indeed rendered so faint in passing through it that, when collected in the focus of a burning glass, they would scarce kindle brown paper." Franklin connected the dry fog and the reduced solar radiation with the severe winter of 1783/1784 in Europe and eastern North America, and he proposed that the Icelandic eruption of that time was to blame.

The connection between large volcanic eruptions and worldwide perturbations of the optical properties of the atmosphere was established by the classic study of the Krakatoa Commission (Russell & Archibald 1888) in the aftermath of the changes in the atmosphere seen after the Krakatau eruption in 1883 (see also Simkin & Fiske 1983). A number of atmospheric optical phenomena were identified, including noticeable dimming and blurring of celestial objects, unusual blue or green color of the Sun and Moon, enhanced sunrises and sunsets with lavender glows that appeared high over the horizon, Bishop's rings (a complex halo around the Sun produced by diffraction of sunlight by small particles, in which the normal order of colors is reversed, with red on the outside), and also unusually

dark lunar eclipses (Flammarion 1884). A link between climate change and volcanic eruptions was also based on later studies that suggested a possible correlation between some eruptions, decreases in solar radiation measured at ground observatories, and short-term coolings of the Earth's surface (Humphreys 1913, Abbot & Fowle 1913; for an early review, see Humphreys 1940); however, in other similar studies the same or other noteworthy eruptions seemed to show no noticeable effect on the global climate (Gentilli 1948, Deirmendjian 1973, Landsberg & Albert 1974, Ellsaesser 1986).

In 1970, a classic study by H. H. Lamb clearly presented the empirical evidence for a volcano/climate connection as understood at that time. Lamb reviewed previous work on the subject, but his most valuable contribution was his tabulation of a chronology of important volcanic eruptions for the period subsequent to AD 1500 and his definition of the volcanic dust veil index (d.v.i.), an estimate of the amount of fine volcanic ash or dust lofted into the upper atmosphere by specific historical eruptions. Lamb concluded that some significant correlations existed between "volcanic eruption years" with high d.v.i. values and climatic cooling, but he stressed that in some cases where the d.v.i. was assessed largely on the evidence of temperature variation, one was in clear danger of arguing in a circle when investigating the possible effects of eruptions on climate. Newhall & Self (1982; see also Simkin et al 1981) attempted to further quantify volcanic "explosivity" in their Volcanic Explosivity Index (VEI), which combined estimates of eruption volume with explosive energy as evidenced by the height of the eruption plume. Hirschboeck (1980) proposed another, but simpler, index based largely on the volume of the eruption. By that time, however, it was clear that the composition of the volcanic ejecta, particularly the amount of sulfur volatiles released, had an importance above and beyond that of the total amount of ash ejected. The geographic location, time of year, and prevailing climatic conditions (e.g. phase in the quasi-biennial oscillation cycle) were also seen to be critical factors in determining the spread and lifetime of volcanic aerosol clouds.

## NINETEENTH AND TWENTIETH CENTURY ERUPTIONS: SULFUR IS THE KEY

Although most workers prior to the late 1960s stressed the importance of "volcanic ash" in the stratospheric clouds (e.g. Jacobs 1954, Mitchell 1961), Lamb (1970) and Deirmendjian (1973) both recognized a possible connection between sulfur gases (primarily $SO_2$ and $H_2S$) injected into the upper atmosphere by volcanic eruptions and the evidence discovered by Junge et al (1961) for a supposedly permanent layer of sulfate aerosols

(consisting largely of small droplets of sulfuric acid) in the stratosphere at around 25 km. It was later shown that the majority of the $H_2SO_4$ aerosols in the so-called Junge Layer were volcanic in origin (Castleman et al 1974).

A number of studies followed that focused on photochemical reactions and nucleation of sulfuric acid aerosols in the lower stratosphere. It was soon well established that the bulk of volcanic "dust" veils consisted of fine droplets of sulfuric acid [see Turco et al (1982) for a review]. Most of the volcanic ash fell out of the stratosphere in a few months, while the aerosols continued to nucleate and grow, creating the volcanic cloud that spread over wide areas of the globe and persisted for several years (Pollack et al 1976, Cadle et al 1976, 1977, Hunt 1977, Capone et al 1983). In addition, HCl and water vapor that are injected into the stratosphere during an eruption may have significant effects on the ozone concentrations (Hofmann 1987, Pinto et al 1987).

Stratospheric aerosols affect the global radiation budget by absorbing and, more importantly, backscattering incoming solar radiation (although they also absorb some outgoing infrared radiation from the ground). Absorption and backscattering of solar radiation should cause a cooling of the lower atmosphere and the surface. The absorption of infrared radiation should also cause an increase in the stratospheric temperatures (see Turco et al 1982). The volcanic signal expected in hemispheric or zonal surface temperature records in historical times, however, is about the same as the background interannual variations in temperature. Several studies have made use of the method of "compositing" or "superposed epoch analysis," in which the temperature records of several years bracketing a number of different eruptions are superposed in order to strengthen the contrast between the possible volcanic signal and background noise (Figure 1). These studies identified a statistically significant average temperature decrease of about 0.2 to 0.5°C for 1 to 3 years following the times of known nineteenth and twentieth century eruptions (Mitchell 1961, Mass & Schneider 1977, Taylor et al 1980, Self et al 1981, Angell & Korshover 1985, Lough & Fritts 1987). Other statistical studies have come to similar conclusions regarding the magnitude and duration of cooling after volcanic eruptions of the past 100 years (for a review, see Angell & Korshover 1985). A recent superposed epoch analysis of Northern Hemisphere sea-surface temperatures after major eruptions of the last 100 years, however, did not show any consistent response of posteruption cooling (Parker 1985), but sea-surface temperatures are expected to be less responsive to short-term temperature perturbations, and other factors such as the Southern Oscillation/El Niño phenomenon may be masking the volcanic climate signal.

Another approach is to focus on the largest and/or best documented

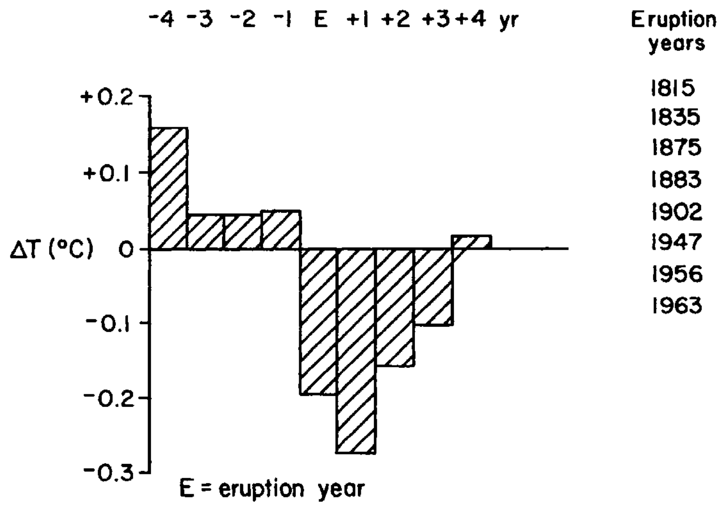


*Figure 1* Composite plot of the temperature departure for the Northern Hemisphere in the four years immediately before and after some large nineteenth and twentieth century eruptions (after Self et al 1981).

volcanic perturbations and to reexamine them in detail. Hansen et al (1978) examined the 1963 eruption of Mt. Agung on the Indonesian island of Bali, which occurred at a time when tropospheric and stratospheric temperatures were being routinely measured (Newell 1970, Newell & Weare 1976) and accurate measurements of aerosol optical depth were being made at a number of observatories (Volz 1970). [Optical depth is equal to the negative natural logarithm of the attenuation of incident light, or $\tau = -\ln(I/I_0)$, where $I_0$ and $I$ are the initial and final light intensity, respectively.] High-altitude aircraft above 20 km could also directly collect stratospheric aerosols for analysis (Mossop 1964).

Hansen et al (1978) calculated the expected effect on the stratospheric and tropospheric temperatures by using the measured time history of aerosol optical depth and a simple one-dimensional radiative/convective climate model. They then compared these calculated temperature changes with the observed temperature perturbations. The theoretical results agreed with the observation that stratospheric temperatures rose by 4 to 8°C in the region from 10°N to 30°S, while surface temperatures in the region from 30°N to 30°S showed a decrease of a few tenths of a degree over a period on the order of a year. Hansen et al (1981) later confirmed, to a large extent, their earlier theoretical results for surface cooling as well as the simpler box-model predictions of Schneider & Mass (1975) and Harshvardhan & Cess (1976). Further studies of the effects of volcanic aerosols on climate using more sophisticated two-dimensional climate models have in general confirmed the empirical evidence for cooling of a few tenths of a degree Celsius following large historic eruptions (Robock 1981, 1984, Chou et al 1984, McCracken & Luther 1984).

A major finding in both the statistical and individual studies of volcanic perturbations of the atmosphere is that relatively small volcanic eruptions (measured by the total volume of magma ejected as pumice and ash) such as that of Mt. Agung in 1963 [estimated volume of ejected magma of only 0.3–0.6 $km^3$, dense-rock equivalent (DRE); Rampino & Self 1984a] can lead to a relatively dense aerosol cloud, totaling perhaps 10 megatons (Mt) of $H_2SO_4$ aerosols in the specific case of Agung [at least in the Southern Hemisphere; the Northern Hemisphere stratosphere contained only about one fifth of this mass of aerosols (see Table 1)]. By contrast, the much larger Krakatau eruption in 1883 [$\sim$10 $km^3$ (DRE) of ejected magma] produced a cloud only five times more massive ($\sim$50 Mt of $H_2SO_4$ aerosols). Obviously a number of factors, both volcanological and meteorological, involving the amount of $H_2SO_4$ aerosols created in the upper atmosphere and their potential for widespread distribution come into play in determining the impact of any particular volcanic eruption on the climate.

Volcanologists have attempted to measure the amount of sulfur volatiles emitted by past eruptions through analysis of the composition of the solid products (pumice, scoria, lava, or fine ash). One method is to determine the sulfur volatile content in glass inclusions in crystals of minerals that formed within the magma chamber just prior to the eruption; this gives a

**Table 1** Estimates of stratospheric aerosols and climatic effects of some volcanic eruptions[a]

| Volcano | Latitude | Date | Stratospheric aerosols (Mt) | Northern Hemisphere $\tau_D$ | Northern Hemisphere $\Delta T$ (°C) |
|---|---|---|---|---|---|
| Explosive eruptions | | | | | |
| St. Helens | 46°N | May 1980 | 0.3 | <0.01 | <0.1 |
| Agung | 8°S | March/May 1963 | 10 | <0.05[b] | 0.3 |
| El Chichón | 17°N | March/April 1982 | 20 | 0.15 | <0.4 |
| Krakatau | 6°S | August 1883 | 50 | 0.55 | 0.3 |
| Tambora | 8°S | April 1815 | 200 | 1.3 | 0.5 |
| Rabaul? | 4°S | March 536 | 300 | 2.5 | large? |
| Toba | 3°N | −75,000 yr | 1000? | 10? | large? |
| Effusive eruptions | | | | | |
| Laki | 64°N | June 1783 to February 1784 | $\sim$0 | Locally high[c] | 1.0? |
| Roza | 47°N | −14 Myr | 6000? | 80?[d] | large? |

[a] References: Rampino & Self (1984a) and text. Optical depths are visual, direct beam.
[b] Southern Hemisphere $\tau_D \approx 0.2$.
[c] Aerosols were mostly tropospheric.
[d] If the aerosols were dispersed globally, the average Northern Hemisphere optical depth would have been about 40.

measure of preeruption sulfur. Knowing the volume of magma erupted, one can then estimate the sulfur volatile release by determining the amount of sulfur contained in the erupted ash and taking the difference (Sigurdsson 1982, Devine et al 1984). These methods are currently being refined (Sigurdsson et al 1985).

Since a positive general correlation has been established between the solubility of sulfur and the iron content in a magma, basaltic (mafic) magmas tend to be richer in dissolved sulfur than more silicic magmas. Sulfur release into the atmosphere from a basaltic eruption may be an order of magnitude greater than that of a silicic eruption of similar volume, but this is balanced in climatic impact by the fact that silicic eruptions in general are more explosive and therefore tend to create eruption columns that reach well into the stratosphere (Wilson et al 1978). Some eruptions, however, may be "anomalously" rich in sulfur volatiles with regard to their major element chemistry, such as was the case for the 1982 eruption of El Chichón (Table 1), which is discussed later.

Analyses of volcanic emissions show that sulfur is emitted mostly as sulfur dioxide ($SO_2$) and also as hydrogen sulfide ($H_2S$), which is soon oxidized to $SO_2$. In the stratosphere, the sulfur dioxide reacts with hydroxyl ($OH^-$) radicals produced by the photodissociation of water vapor. Gaseous sulfuric acid condenses on minute seed particles of dust (possibly volcanic or meteoritic) or on ions or small clusters of molecules. The photochemical reactions may be protracted, with complete conversion of emitted sulfur gases into aerosols taking weeks to months.

The residence time of the aerosols depends upon the dynamics of nucleation and growth of the droplets. After the initial input of sulfur volatiles and the conversion to droplets, the volcanic aerosols typically have a modal diameter of about half a micron [see Turco et al (1982) for a comprehensive review of observations and theory related to stratospheric aerosols]. For historic eruptions of all sizes, from those just capable of stratospheric injection (e.g. Fuego in 1974) to the largest known (e.g. Tambora in 1815), the *e*-folding time for fallout of the stratospheric aerosols has been observed to be about one year (Stothers 1984a). This means that for significant eruptions (those that create more than 1 Mt of stratospheric sulfuric acid aerosols) the stratospheric aerosol optical depth can be perturbed for several years.

## INFORMATION FROM ICE CORES

Reasonably continuous, direct estimates of atmospheric optical depth from astronomical observations of the Sun, Moon, and stars are available only for the time period since 1883. During this period, changes in the

atmospheric transparency have been correlated with significant volcanic eruptions (e.g. Pollack et al 1976). A major problem is to establish methods of estimating the amounts of sulfur aerosols created by significant eruptions prior to that time. In an important paper, Hammer et al (1980) presented evidence from the yearly ice layers in deep Greenland ice cores for sharp increases in acidity that coincided with the times of historic eruptions. They used the acid concentrations to estimate the global stratospheric aerosol burden in these volcanic years.

The ice-core method has several limitations, however, including the fact that eruptions in relatively high northern latitudes can produce especially large acidity spikes because of closeness of the volcanoes to Greenland. For example, the years 1963 and 1964 are associated with a noticeably high acidity peak in Greenland ice cores—enough to suggest about 20 Mt of aerosols in the Northern Hemisphere stratosphere if the source were the equatorial Agung eruption. But we know from direct atmospheric observations that less than one fifth of this amount was actually spread in the stratosphere north of the equator from the Agung eruptions in Bali (Volz 1970). The Greenland acidity spike is too high to be the result of Agung aerosols and is almost certainly due to tropospheric transport from smaller nearby eruptions such as the ongoing Surtsey eruptions off Iceland (Cronin 1971). Significantly, Koerner & Fisher (1982) detected no excess ice acidity for the years 1963 and 1964 on Ellesmere Island, Canada, whereas Delmas & Boutron (1980) and Legrand & Delmas (1987) did discern a strong acid signal in Antarctic ice which could be attributed to Agung. Icelandic eruptions in general are overrepresented in Greenland ice cores (Hammer 1984). Globally, however, the effectiveness of transport of acid aerosols to Greenland may also vary with seasonal and year-to-year changes in atmospheric circulation patterns (Hammer et al 1980).

It is worth emphasizing that if an eruption, even a moderately large one, does not inject sufficient sulfur into the atmosphere it will not appear above the noise level in the polar ice acidity record. This means that most eruptions with potential climatic impact are expected to leave a discernible trace in polar ice, although the amount deposited may not be proportional to the actual mass of sulfur produced, for the meteorological reasons just discussed. Probably any explosive eruption bigger than Krakatau's in 1883 can be detected in one or both of the polar ice sheets, because so much magma is erupted that the sulfur release is bound to be fairly large in any case.

One way of correcting for all these problems is by making comparisons with ice cores from several other localities to get a better estimate of the global distribution of the aerosols. Although such a method of calibration holds promise, for example, with the conductivity records of the Quelccaya

ice core from the Peruvian Andes (Thompson et al 1986) and the Yukon ice core (Holdsworth et al 1986), it has proven to be difficult even with cores from different parts of the Greenland Ice Sheet (Herron 1982). The accumulation rate of snow in Antarctica is much less than that in Greenland, and hence the yearly ice layers there are generally thinner and more difficult to count and date accurately (Delmas et al 1985). Obviously, the best way of calibrating the ice-core acidity records as a record of global stratospheric aerosols is to identify, if possible, the location of the specific eruptions that produced the acid spikes.

It is worth noting that some periods of enhanced ice-core acidity and microparticle accumulation, lasting for decades and longer, coincide with historic cool intervals such as the Little Ice Age (Hammer et al 1980, Porter 1981, 1986, Thompson & Mosley-Thompson 1981, Thompson et al 1986). It is possible, therefore, that episodes of greater-than-average volcanism may modulate the climate over periods of tens to hundreds of years (for a review, see Bryson & Goodman 1980).

## MT. ST. HELENS AND EL CHICHÓN: A STUDY IN CONTRASTS

The spectacular Mt. St. Helens eruption of May 1980 produced a stratospheric cloud of ash but released a relatively small amount of $SO_2$ into the Northern Hemisphere stratosphere, with the result that only about 0.3 Mt of sulfuric acid aerosols were produced (Table 1) and no significant climatic effects [aside from a local daytime cooling the next day for stations downwind of the ash (Robock & Mass 1982)] were detected (Newell & Deepak 1982). In March–April 1982, however, the Mexican volcano El Chichón erupted explosively and sent a huge cloud rich in $SO_2$ up to about 26 km in the stratosphere. Observations from the ground and by satellite showed that this eruption was having a large impact on the stratosphere, and the spread of the cloud could be tracked accurately.

El Chichón provided the test case for which volcanologists and atmospheric scientists had been waiting (see reviews by Rampino & Self 1984b, Hofmann 1987). Like St. Helens, it was a small eruption volumetrically, producing only about 0.3 to 0.4 $km^3$ (DRE) of magma, but it was extremely rich in sulfur (derived perhaps from deposits of $CaSO_4$ beneath the volcano); thus, while the volcanic ash contribution to the atmosphere was small, the sulfuric acid aerosol contribution was considerable, about 20 Mt (Table 1). This is enough, theoretically, to lower the surface temperatures in the Northern Hemisphere a few tenths of a degree Celsius, and the year 1982 showed such a cooling (Table 1), although it seems that the cooling began with colder than average weather from January to March—before

the El Chichón eruptions. But the summer was cool, with a unique snowfall in Vermont in August. Kelly & Sear (1984) proposed that Northern Hemisphere eruptions can cause cooling within the first 2 to 3 months after an eruption. Longer term effects from El Chichón were predicted by some models (Robock 1984), and Reiter & Jäger (1986) suggested that the cold winter of 1984/1985 was possibly related to lingering aerosols from the eruption.

The severe El Niño event of 1982/1983 added some confusion as to climatic cause and effect. Handler (1984), among others, has suggested that the El Chichón aerosol cloud either triggered the El Niño or led to its intensification—a proposal that has generated a good deal of debate. (It is interesting to note that the 1963 Agung eruption was also followed by an "off-season" El Niño event.)

## THE GREATEST HISTORIC ERUPTIONS AND THEIR ATMOSPHERIC EFFECTS

With the Greenland ice-core record of acidity as a guide to notable "eruption years" (Hammer et al 1980, Hammer 1984), it has become possible to attempt to identify the source volcanic eruptions for the acid-rich layers deposited on the polar ice sheets. For more recent historical times it is relatively easy to pinpoint the eruptions that caused acid spikes (for example, Krakatau in 1883 and Tambora in 1815), but even here the situation may be more complicated than it first appears. Mt. Augustine in Alaska also erupted in 1883, and the Mayon eruption in the Philippines in 1814 may have contributed some acids to the ice layers of 1815 and 1816 (Stothers 1984a). Asama in Japan erupted at the same time as Laki during 1783.

In order to identify the extent of aerosol clouds and possible sources of ice-core acidity spikes prior to AD 1500, it has been necessary to search through historical records for evidence both of local eruptions (mostly in the Mediterranean region) and of the atmospheric perturbations caused by aerosol clouds from perhaps distant eruptions. A virtually complete search of the European records prior to AD 630 (Stothers & Rampino 1983a,b) turned up occasional evidence of significant atmospheric disturbances, such as a dim Sun and Moon, unusual atmospheric optical phenomena, and unusually cold weather accompanied by crop failures and famine. Similar work is now being done for the extensive Chinese historical records (Pang & Chou 1984, 1985, Pang et al 1986). It will be useful in this review to summarize the atmospheric and climatic effects occurring in some of the most severe and better known of the historical eruption years.

## *1816: The Tambora Effect and the Year Without a Summer*

The year 1816 has gone down in the annals of climate history as the "Year Without a Summer" and "Eighteen Hundred and Froze to Death" (Stommell & Stommell 1983). In fact the entire decade from 1810 to 1820 was a time of noticeably cool temperatures in the Northern Hemisphere, and this has been correlated by some authors with the low sunspot maximum in 1816 (e.g. Humphreys 1940). The unusual weather in 1816 followed the spectacular April 1815 eruption of Tambora volcano on Sumbawa Island in Indonesia—one of the largest known ash-producing eruptions [150 $km^3$ of ash and pumice, equal to about 50 $km^3$ (DRE) of magma] in the last 10,000 years (Stothers 1984a, Self et al 1984).

Ash fallout was noted over an area in excess of $4 \times 10^5$ $km^2$ (and probably fell over an area of more than $10^6$ $km^2$); darkness lasted for up to 2 days at distances of 600 km from the volcano. The eruption rate and the area of ash dispersal both suggest that the eruption column may have reached 50 km into the stratosphere. The volcanic cloud traveled around the world, and within 3 months its optical effects were observed at distant locations in Europe. For example, around the end of June, and later in September, several observers near London reported prolonged and brilliantly colored sunsets and twilights.

The following year (1816) was marked by a persistent dry fog, or dim Sun, as reported in the northeastern United States. The haze was clearly located above the troposphere, since neither surface winds nor rain dispersed it and because the total lunar eclipse of 9–10 June was extremely dark. Stothers (1984a) has derived a time history of the optical properties of the Tambora aerosol cloud (Figure 2) by using indicators of reduced atmospheric transmissivity such as dimming of the Sun (shown by increased naked-eye visibility of sunspots) and dimming of starlight (noted by astronomical observers). The calculated aerosol mass for Tambora (Table 1) is in good agreement with estimates based on the 4-yr-long (1815–1818) acidity enhancement in the Crête, Greenland, ice core (Hammer et al 1980). Fallout from this eruption has probably also been detected in Antarctic ice (Thompson & Mosley-Thompson 1981, Delmas et al 1985, Legrand & Delmas 1987).

The exceptional meteorological conditions spawned by the explosion started with a hot, followed by an "extremely cold," pocket of air directly under the tropospheric ash clouds (at least at Banjuwangi, 400 km from the volcano) and then continued with freezing temperatures in Madras, India, two weeks later (Stothers 1984a). Analogous studies of the effects of the Canadian wildfires of 1950 (Wexler 1950) and the Siberian wildfires of 1915 (Seitz 1986) have shown that surface temperatures in those cases

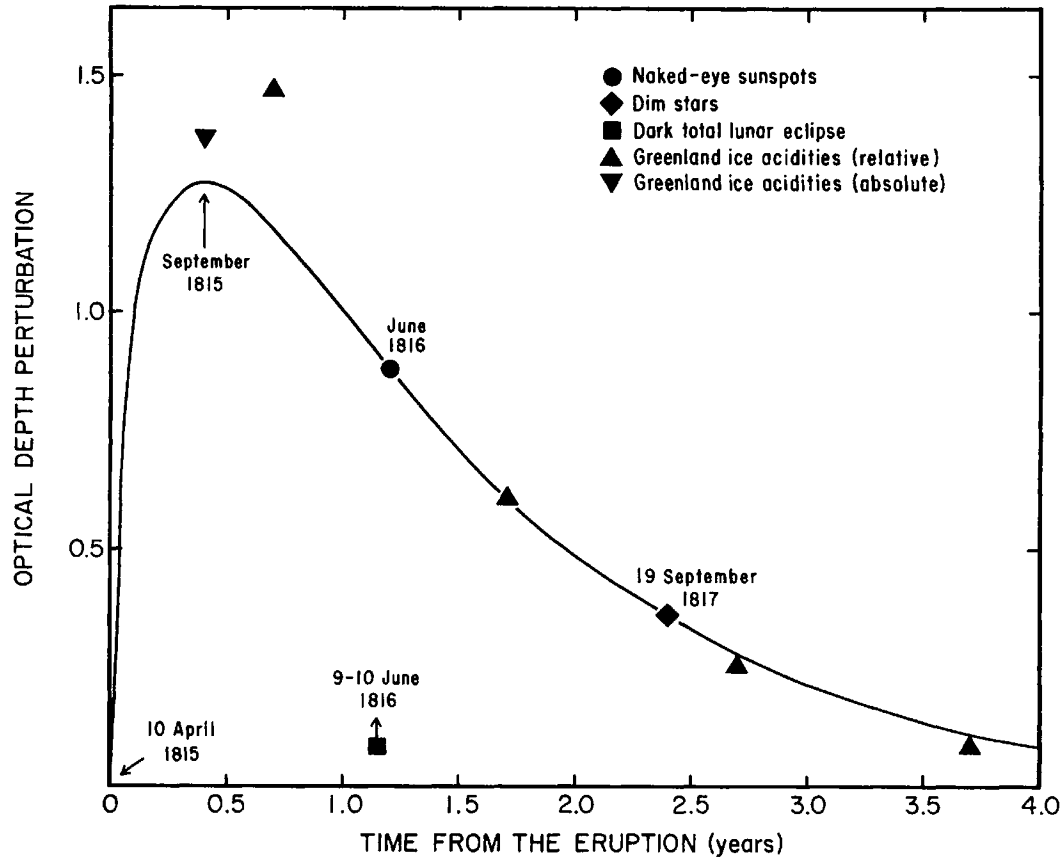


*Figure 2* Excess visual optical depth at northern latitudes as a function of time reckoned from the date of the 1815 Tambora eruption. The plotted point for 9–10 June 1816 is only the lower limit to the true value (after Stothers 1984a).

dropped several degrees Celsius in areas that were thickly covered by high-altitude smoke clouds, as a result of the attenuation of the incoming solar flux. On the other hand, low-altitude smoke clouds heated up the boundary layer locally. Since volcanic ash sufficiently resembles sooty smoke, the meteorological analogies probably can be validly made in a qualitative way.

The summer of 1816 in western Europe was cool and exceedingly wet; crop failures (compounded by the aftereffects of the Napoleonic Wars) led to famine, disease, and social unrest, referred to by Post (1977) as "The Last Great Subsistence Crisis in the Western World." Kelly et al (1984) have suggested that an important effect of volcanic aerosol clouds is to produce a marked drop in surface pressure across the midlatitudes of the North Atlantic sector, leading to a southward shift in the track taken by middle-latitude cyclones. A major anomaly would thus be centered over England and would extend over much of western Europe, giving rise to a cold, wet summer. In support of this, Kelly et al have reconstructed

pressure anomaly charts of Europe based on the available data; these charts are dominated by negative pressure anomalies over Europe beginning in early 1816. Data from Manley (1974) show that the summer months of 1816 in central England were about 1.5°C cooler than during the summer of 1815. The dismal European summer is credited with having inspired Mary Shelley to write *Frankenstein*, and Lord Byron his poem *Darkness*.

In North America, records of Hudson's Bay Company posts on the eastern side of Hudson Bay show that the summers of 1816 and 1817 were the coldest of any in the modern record (Wilson 1985a,b). Tree-ring data from northern and western Quebec support these observations (Filion et al 1986, Jacoby et al 1987). The distribution and severity of sea ice in Hudson Strait in 1816 suggests prevailing northerly or northwesterly winds, which again supports the idea that these years were marked by the development of strongly meridional atmospheric circulation patterns allowing southward penetrations of Arctic air across eastern North America and western Europe (Catchpole & Faurer 1983). Outbreaks of unusually cold weather during the spring and summer of 1816 in eastern Canada and the eastern United States are well documented (Post 1977, Stommel & Stommel 1983, Hamilton 1986). For example, the summer of 1816 was the coldest in New Haven, Connecticut, for the entire period from 1780 to 1968 (Landsberg & Albert 1974). From late spring through the summer, repeated frosts in New England caused crop failures, resulting in poor harvests and food shortages.

The outbreaks of cold weather and raininess during the summer months of 1816 are seen clearly in a number of other climatic indicators from around the world, from lateness in the grape harvests in France (Stommel & Swallow 1983) to frost damage rings in trees in the western United States (LaMarche & Hirschboeck 1984) and in South Africa (Dunwiddie & LaMarche 1980).

On a zonal to hemispheric basis, the deviation of annual mean temperature is more difficult to assess, since the station coverage in 1816 was very spotty. Using W. Köppen's compilation of temperature data, Stothers (1984a) finds an average deviation for the "Northern Hemisphere" in 1816 of $-0.4$ to $-0.7$°C, whereas the value for northern midlatitudes is about $-1.0$°C. This agrees with other estimates based on less data and somewhat different averaging (Lamb 1970, Rampino & Self 1982, Angell & Korschover 1985).

## *1783: The Fire Fountains of the Laki Fissure Eruption*

Franklin's observations of the "dry fog" produced by the Laki (or Lakagígar) eruption have focused the attention of climatologists and volcanologists on the events surrounding this unusual eruption and its after-

math. The Laki eruption began in June 1783 and lasted for 8 months. The eruptions were not the typical explosive eruptions of the sort that produce great amounts of pumice and ash; Laki was primarily a fissure basalt, lava-flow type, and it erupted about 12.3 $km^3$ of lava, the bulk of it coming from a 13 km length of fissure during June and July, in the first 50 days of the eruption (Thorarinsson 1969). From eyewitness accounts, it appears that during the first days the eruption was extremely violent, with "enormous" Hawaiian-type lava fountains. Thorarinsson (1969) estimated that about 0.3 $km^3$ (DRE) of tephra was erupted, mostly during this early violent phase, and fine ash from the eruption fell as far away as northern Europe.

The effects of the eruption in Iceland were disastrous. The toxic volcanic gases and aerosols created a "blue haze" that spread all across the island and led to the destruction of the summer crops. About 75% of the livestock in Iceland died, and the resulting "Blue Haze Famine" claimed 24% of the Icelandic population. The dry fog reported by Franklin was also reported by others in Europe (for example, Gilbert White in England) and was even seen in Asia and North Africa (Holm 1784, Russell & Archibald 1888). Wood (1984) has established from eyewitness reports that much of the haze over Europe lay in the lower troposphere. However, the reported visibility of the haze high up in the Alps and its continued observability throughout Europe for weeks in spite of changing wind directions and rainfall suggest that it extended upward at least into the upper troposphere. The haze in Europe appeared most intense during June and July, precisely the same months that Laki was most active. The eruption ceased by early February 1784, but the dry fog had already largely disappeared by the end of December 1783 (Stothers et al 1986). In three Greenland ice cores, Hammer et al (1980) and Hammer (1984) found the acidity of the 1783 layers to be extraordinarily high, but no excess acidity was found in the 1784 layers, contrary to what one would expect if the stratosphere had been significantly loaded with aerosols. Moreover, the total lunar eclipse of 10 September 1783 was not unusually dark (Maclean 1984). Thus, the eruption column of fine ash and volcanic gases from Laki must have normally reached only up to, at most, the tropopause (8 to 11 km during the Icelandic summer).

In Iceland itself, a prompt and extreme cooling at the surface was observed directly under the ash clouds during the summer of 1783 (Stephensen 1813). Elsewhere, as Sigurdsson (1982) has shown from early Northern Hemisphere temperature records, an abnormal temperature decline began in the autumn of 1783 and reached a minimum in the period from December 1783 to February 1784. This period showed the lowest mean winter temperature in 225 years, which was 4.8°C below the long-

term average. The spring, autumn, and winter mean temperatures for 1784 and 1785 were below normal as well. Northern tree-ring data also indicate cold growing seasons during 1783 and 1784 (Oswalt 1957, Filion et al 1986). Theoretically, very fine solid particles and *small* tropospheric aerosols in continuous production, with extensive horizontal dispersion, might have been able to initiate such a cooling (see Hansen et al 1980).

## *536: The Mystery Cloud*

The densest and most persistent dry fog in recorded history was observed during AD 536–537 in Europe and the Middle East (Stothers & Rampino 1983a, Stothers 1984b) and in China (K. D. Pang & H.-h. Chou, in Weisburd 1985). In the Western literature five reliable contemporary descriptions of the atmospheric conditions of 536–537 exist. According to one contemporary writer (probably John of Ephesus), conditions in Mesopotamia (30° to 37°N) were such that "the sun was dark and its darkness lasted for eighteen months; each day it shone for about four hours, and still this light was only a feeble shadow . . . the fruits did not ripen and the wine tasted like sour grapes." The winter in Mesopotamia was exceptionally severe, with freak snowfalls and much hardship. In Italy, a high government official (Cassiodorus Senator, not mentioned by Stothers & Rampino) wrote in the late summer of 536: "The sun . . . seems to have lost its wonted light, and appears of a bluish color. We marvel to see no shadows of our bodies at noon, to feel the mighty vigor of the sun's heat wasted into feebleness, and the phenomena which accompany a transitory eclipse prolonged through almost a whole year. The moon, too, even when its orb is full, is empty of its natural splendor. . . . We have had . . . a spring without mildness and a summer without heat . . . the months which should have been maturing the crops have been chilled by north winds . . . rain is denied . . . the reaper fears new frosts" (Cassiodorus Senator AD 536). Cold and drought finally succeeded in killing off the crops in Italy and Mesopotamia and led to a terrible famine in the immediately following years. These and other accounts of the time read remarkably like Franklin's and others' modern descriptions of the "dim Sun" conditions following known volcanic eruptions.

It is possible to estimate from these historical accounts that such a pronounced reduction in solar brightness would require an excess visual atmospheric optical depth of $\tau_D = 2.5$ (Stothers 1984b). Under these conditions, at maximum altitude, the Sun (and Moon) would have appeared about 10 times fainter than normal, thus accounting for the reported darkening; scattered sunlight would have illuminated the rest of the sky. The mystery cloud first appeared in the Mediterranean region in late March of 536. Observers at 41 to 42°N reported effects lasting for 12 to

15 months, whereas at 30 to 37°N the duration recorded was 18 months. This suggests that the eruption that produced the aerosols was situated somewhere to the south; a possible source is the large eruption of Rabaul (4°S), on the island of New Britain off New Guinea, radiocarbon dated to AD 540 ± 90 (Heming 1974).

Similar atmospheric effects were seen in China during the same years. Pang & Chou (see Weisburd 1985) have recently noted, for example, that the bright star Canopus was not visible when looked for at the equinoxes of 536. They have also documented and reconstructed the distribution of summer snows and frosts, drought, and famine throughout China in the years 536–538. The situation in China clearly paralleled that of Europe and the Middle East; the mystery cloud and the anomalously cold weather seem to have occurred throughout at least a large portion of the Northern Hemisphere. Moreover, a deep Greenland ice core shows a high acidity at roughly this date, originally given as 540 ± 10 (Hammer et al 1980, Herron 1982), but later revised to 516 ± 4 (Hammer 1984) and perhaps still in need of revision.

### *44 BC: Caesar's Death and the Year of the Failing Sun*

Another significant dimming of the Sun is reported in the ancient literature for 44 BC and the subsequent two years. In the Western records (Stothers & Rampino 1983a), Plutarch, writing ca. AD 100, gives the fullest account of the "dim Sun" conditions after the murder of Julius Caesar: "For during all that year its orb rose pale and without radiance, while the heat that came down from it was slight and ineffectual, so that the air in its circulation was dark and heavy owing to the feebleness of the warmth that penetrated it, and the fruits, imperfect and half ripe, withered away and shrivelled up on account of the coldness of the atmosphere." Ovid (ca. AD 10) describes the Moon as "bloody" and Venus as "darkly rusty" in 44 BC, while Calpurnius Siculus (ca. AD 60) alludes to the "bloody" color of the comet of 44 BC (not cited by Stothers & Rampino). One possible cause for these atmospheric conditions was an eruption of Etna dated to the same year. As Vergil relates, "Mighty Etna . . . from its burst furnaces breathes forth flame; and . . . all Sicily moans and trembles, veiling the sky in smoke." Livy and, later, Pliny the Elder independently testified to the exceptional magnitude of this explosive Etnan eruption. Etna's last large eruption had occurred about 77 years earlier. (We now think that Lucan's and Petronius's apparent allusions to an eruption in 50–49 BC actually refer to the 44 BC eruption.)

Atmospheric effects in China were reported in the *Chronicles of the Han Dynasty* (Schove 1951, Pang & Chou 1984). For example, in April–May 43 BC, "It snowed. Frosts killed mulberries." In May–June, "The sun was

bluish white and cast no shadow. At high noon there were shadows but dim." In October, "Frosts killed crops, widespread famine. Wheat crops damaged, no harvest in autumn." The historical data and the Greenland ice-core acidity record support the idea of multiple eruption clouds in the years from 44 to 42 BC (Stothers & Rampino 1983a, Pang et al 1986). A strong 3-yr-long acidity peak in two Greenland ice cores has been dated around $50 \pm 4$ BC (Hammer et al 1980, Hammer 1984; see also Herron 1982), and it probably correlates with the veiled Sun and other peculiar optical phenomena of 44–42 BC.

## COMETARY WINTER AND NUCLEAR WINTER

Interest in the aftermath of a proposed collision of an asteroid or comet with the Earth at the time of the Cretaceous-Tertiary mass extinctions (66 Myr BP) has led to scenarios of Sun-blocking dust clouds originating from the huge cratering event, and smoke clouds rising from widespread wildfires [see Alvarez (1986) for a review]. These studies created the impetus for an analysis of the possible atmospheric effects of the sooty smoke from burning cities in the wake of a nuclear war (Crutzen & Birks 1982, Turco et al 1983). The initial "nuclear winter" simulation studies, based on the results of simple one-dimensional radiative/convective climate models, suggested the possibility of drastic temperature decreases of up to 30°C, with subfreezing conditions for weeks to months over large portions of the Northern Hemisphere and effects penetrating into the Southern Hemisphere as well, after a "baseline" nuclear exchange (Turco et al 1983, 1984b). This work prompted several research groups to study the effects of smoke generated by nuclear war, and the results obtained touched off a debate regarding the uncertainties in the amount of smoke that could be lofted to high altitudes and the scale and severity of the climatic effects of nuclear wildfires (for a review, see Colbeck & Harrison 1986).

Two independent study groups (National Research Council 1985, SCOPE 1985) concluded that the climatic effects could be severe, but that there were many uncertainties in the nuclear winter analyses. The most recent studies, using more sophisticated climate models (GCMs), suggest that the cooling would be much less severe though still significant ("nuclear autumn"), with worst case (July) decreases of perhaps 5°C in low latitudes (10–30°N) and 10–15°C at higher northern latitudes, lasting only a few weeks and with considerable unevenness. Most of the reduction in the degree of cooling is related to the probable removal of 75% of the smoke from the atmosphere within the first 30 days, as well as to patchiness in the smoke distribution and to the moderating effects of the oceans in the climate system (Thompson & Schneider 1986, Covey 1987).

## VOLCANIC WINTER?

### *Large Explosive Eruptions*

We have thus far discussed the climatic aftereffects of a number of the greatest historical volcanic eruptions. The nuclear winter debate raised a suggestion that the atmospheric aftereffects of these volcanic eruptions might be used as a basis for estimating the severity of cooling from dense smoke clouds (Maddox 1984, Brown & Peczkis 1984). The differing optical properties between volcanic aerosols and black, sooty smoke from urban fires, however, makes such a comparison difficult (Turco et al 1984a, 1985). More importantly, historic eruptions have produced relatively small amounts of aerosols. But perhaps the historic eruptions can be used as a baseline for estimating the possible atmospheric effects of the largest volcanic eruptions in the geologic past—much larger than recent historic events such as Tambora or Krakatau, or even the mystery eruption of 536. One good example is the Toba eruption in Sumatra about 75,000 years ago, which is the best-known late Quaternary "supereruption," with a recent estimate of the volume of erupted pyroclastics being equivalent to more than 2000 $km^3$ (DRE) of magma (Rose & Chesner 1986).

The Toba ash layer is extraordinarily widespread (Ninkovich et al 1978), and rough calculations, using the same methods as Murrow et al (1980), suggest that a maximum of $\sim 0.8\%$ of the erupted material could be in the form of fine dust $< 2\ \mu m$ in diameter, for a total of about 20,000 Mt of volcanic dust. If only 10% of this dust were injected into the stratosphere, conditions of total darkness could have existed over a large area for weeks to months (see also Kent 1981).

In order to estimate any longer-lasting atmospheric effects, however, it is necessary to calculate the total amount of sulfuric acid aerosols that could have been produced by the Toba eruption. From simply scaling upward from historical eruptions of similar composition magma, Toba is estimated to have been capable of producing between 1000 to 5000 Mt of sulfuric acid aerosols (Rampino et al 1985). For volcanic aerosols, the globally averaged optical depth is $\tau_D = 6.5 \times 10^{-3}\ M_D$, where $M_D$ is the global aerosol loading in megatons (Stothers 1984a). For Toba the equivalent global aerosol optical depths are 6 to 33 (Figure 3). Local, regional, and hemispheric effects could have been greater, depending on the spread of the cloud. These values may be compared with the peak aerosol optical depth of about 2 estimated for the AD 536 mystery cloud or the value of about 1 following the 1815 Tambora eruption. The atmospheric aftereffects of a Toba-sized explosive eruption might be comparable to some scenarios of nuclear winter, although the aerosols are expected to have a longer atmospheric residence time than would the nuclear winter smoke.

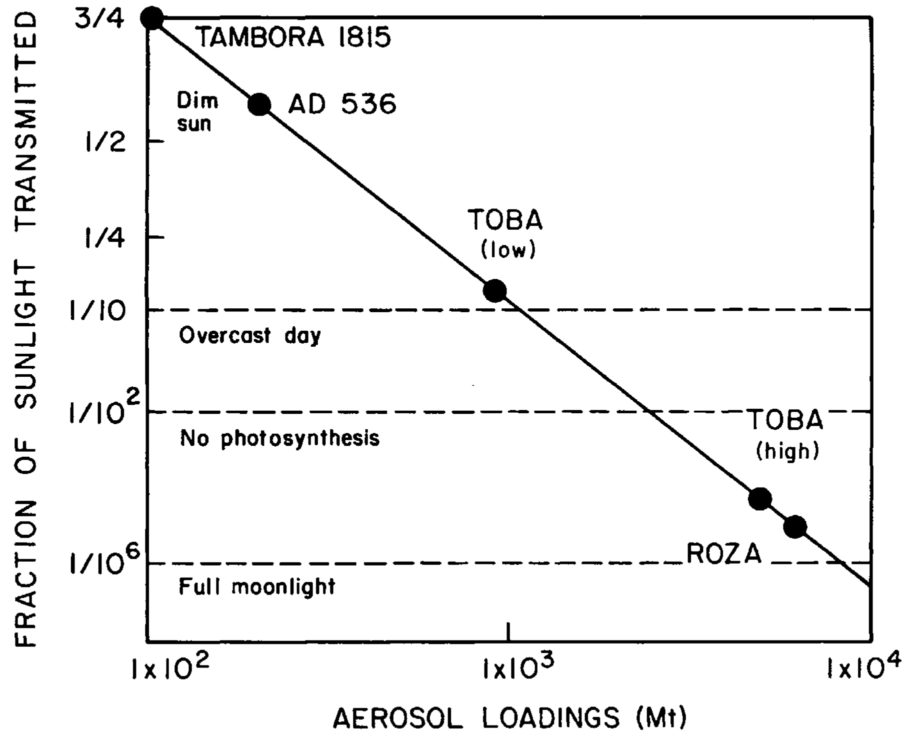


*Figure 3* Fraction of sunlight transmitted through stratospheric aerosol and/or fine-ash dust clouds of different masses (theoretical line, after Turco et al 1984b). Points refer to great historic and prehistoric eruptions (see text).

If such an aerosol cloud could form and persist in the stratosphere, the climatic effects would almost certainly be quite severe. It is important to stress, however, that these are "worst-case" situations, made simply by extrapolating a linear increase in mass of aerosols under the assumption that the behavior of very dense aerosol clouds is not qualitatively different from that of the less dense aerosol clouds observed after historical eruptions. Recent work has shown that differences in aerosol nucleation, saturation, and fallout in dense clouds may affect the concentrations and atmospheric lifetimes of the aerosols. Pinto et al (1987) have recently used a one-dimensional radiative/convective model including aerosol microphysical and photochemical processes to examine the conversion of sulfur dioxide to aerosols in the stratosphere after volcanic eruptions. They find that for successively larger injections of $SO_2$, in the range of 10 to 200 Mt, the processes of condensation and coagulation produce larger particles; these particles have a smaller optical depth and fall out of the stratosphere faster. The rate of $SO_2$ oxidation may also be limited by conversion of OH to $HO_2$ radicals, which could limit the formation of aerosols. These results all suggest that the buildup of $H_2SO_4$ aerosols in the stratosphere might be self-limiting to a degree. However, Pinto et al

have not yet modeled the injection of $SO_2$ burdens of $>1000$ Mt, accompanied by possibly large amounts of water vapor, as could be the case after "supereruptions" such as Toba. In such cases the dynamics of gas to particle conversion and the *e*-folding time of aerosols and ash in the stratosphere and troposphere might be quite different from those in the less dense clouds that have been observed and modeled thus far.

### *Flood-Basalt Eruptions*

As mentioned above, basaltic volcanic eruptions may release an order of magnitude more sulfur volatiles than do silicic eruptions of the same volume (Devine et al 1984). Very recent results indicate that episodes of flood-basalt volcanism in the geologic past have involved the outpouring of up to $10^6$ km$^3$ of basaltic magma over peak time periods of less than a million to a few million years (Bellieni et al 1984, Courtillot & Cisowski 1987, White 1987). Individual eruptions seem to have generated tens to hundreds of cubic kilometers of magma in periods of days to weeks. In the past, "quiet" effusive basaltic eruptions were considered unlikely to produce high-altitude aerosol clouds (Lamb 1970). Recent study has shown, however, that even relatively small historic fissure basalt eruptions, such as the 1783 Laki eruption, have produced widespread aerosol clouds. Theoretical plume modeling of such eruptions indicates that at rapid eruption rates the sulfur volatiles are efficiently released and can be carried to high altitudes in convective plumes rising above large fire fountains (Figure 4).

Stothers et al (1986) have recently considered the possible atmospheric impact of the large flood-basalt eruptions in the geologic past. For example, the Roza flow eruption of the Columbia River Basalt Group (about 14 Myr BP) produced some 700 km$^3$ of basaltic lava in about 7 days (Swanson et al 1975). The estimated eruption rates of $10^4$–$10^5$ m$^3$ s$^{-1}$ from 1 to 10 km fissure lengths are predicted to have generated Hawaiian-type fire fountains about 1 km in height (Wilson & Head 1981) and stratospheric ($>10$ km) eruption plumes (Figure 4).

The quantity of atmospheric aerosols produced by such large basalt eruptions can be roughly estimated by scaling from the known amounts of aerosols generated by the largest modern fissure eruptions, such as Laki in 1783. Laki erupted about 12 km$^3$ of magma and is estimated by various methods to have released about 30 Mt of sulfur (Stothers et al 1986). The sulfur release from the Roza flow eruption is therefore computed to have been (700 km$^3$/12 km$^3$) $\times$ 30 Mt $\approx$ 2000 Mt, equivalent to about 6000 Mt of $H_2SO_4$ aerosols; the corresponding global average optical depth would be about 40. Such a thick aerosol cloud, distributed worldwide, would allow only a small fraction ($10^{-5}$) of sunlight to reach the Earth's surface

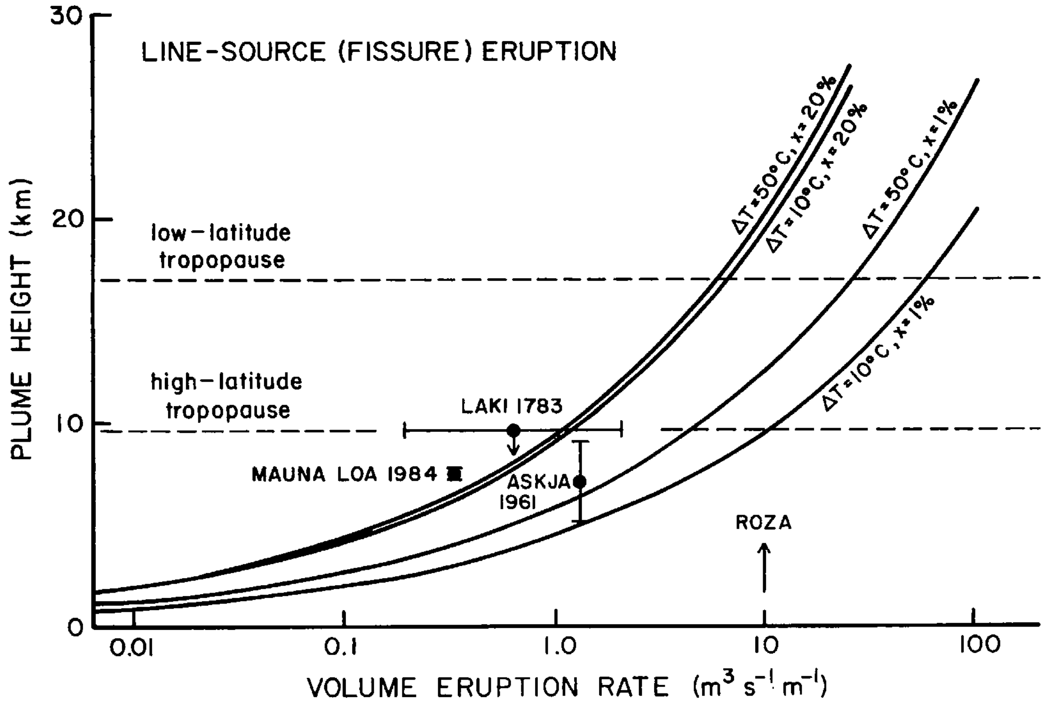


*Figure 4* Convective plume height as a function of volume eruption rate per meter length of fissure for a line-source eruption. Theoretical curves are given for two values of the fine-ash content ($x$) and for two values of the temperature drop of the fountain clasts ($\Delta T$) appropriate for fire-fountain activity. Predicted plume heights for the Roza flow eruption can be read off the observationally calibrated theoretical curves. The plotted plume height for Laki is an observational upper limit (after Stothers et al 1986).

(Figure 3). In this case, barring efficient self-limiting mechanisms, the cloud's atmospheric effects would be comparable to those in recent nuclear winter models, but more extended in time.

## VOLCANISM AND MASS EXTINCTION?

One of the great current debates in geology concerns the cause of mass extinctions. Strong evidence now exists for a comet or asteroid impact at the time of the Late Cretaceous (66 Myr BP) mass extinctions (Alvarez 1986). But recent studies provide evidence that the Deccan Traps flood basalts in India, and perhaps the North Atlantic flood basalts, were erupted at the same time (Courtillot & Cisowski 1987, Officer et al 1987). Episodes of flood-basalt volcanism with peak periods lasting up to a few million years have occurred from time to time in the Earth's history. During the last 250 Myr, there were at least nine major flood-basalt episodes, some involving eruptions in more than one geographic area. When the ages of these flood-basalt episodes are subjected to a formal time-series analysis, they reveal a possible periodicity of roughly 30 Myr (Rampino & Stothers

1986). This is similar to the recent finding of a 26–32 Myr periodicity in the ages of biological mass extinctions (Fischer & Arthur 1977, Raup & Sepkoski 1984) and in the ages of episodes of impact cratering (Rampino & Stothers 1984, Alvarez & Muller 1984). Within the errors of dating, the ages of some of the flood basalts agree very well with the estimated ages of the mass extinctions and impact craters.

What can we infer from this? It may be that some massive outpourings of basalt are triggered by extraterrestrial impacts (Öpik 1958, Urey 1973, Rampino 1987). Or flood basalts might be generated by a quasi-periodic cycle of hotspot activity related to internal mantle dynamics (Loper & Stacey 1983). More speculatively, mass extinctions could be the result both of the aftereffects of a large impact and of related flood-basalt or explosive volcanism. In this case, cometary winters could be succeeded by volcanic winters that prolong the conditions adverse for life.

## CONCLUSIONS

As has been shown in a number of studies, some of the largest historic eruptions are associated with atmospheric perturbations that have had a considerable impact on climate and agriculture. Even the greatest of these historic eruptions, however, was small compared with the very large explosive and effusive eruptions that are well known from the geologic record. A simple scaling-up of the effects of historic eruptions suggests that the much larger eruptions could have brought about severe, short-term coolings or "volcanic winters" over considerable portions of the globe. A very large eruption in the near future might have drastic effects on crop yields and could create food-supply crises in many areas, especially those regions of marginal productivity. Eruptions like these constitute a very real "volcanic hazard" in terms of the number of people that would be affected. There is no question that such large eruptions will recur, the only uncertainty lies in where and when.

Could individual "supereruptions" also lead to greatly prolonged climate cooling? The residence time of volcanic aerosols in the stratosphere is only of the order of a few years; therefore, one must invoke some form of positive climatic feedback to extend the cooling. One possibility is that a few cool summers could lead to significantly increased snow and ice cover at high latitudes, such that the increased albedo would further cool the Earth (see, e.g., Bray 1976). Both the Toba and Roza eruptions occurred at times of relatively rapid climate cooling, but no firm causal connection has been established. Although other large volcanic eruptions are not known to coincide with coolings, certain climatic regimes may be more sensitive to volcanic perturbations. In addition, climatic changes

themselves may be able to influence the incidence and severity of volcanism (Rampino et al 1979). However, such connections remain elusive.

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# Cloudy and clear stratospheres before A.D. 1000 inferred from written sources

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[1] How can observational information about stratospheric transparency in the preinstrumental era be acquired today? It may be reasonably assumed that a high turbidity in the stratosphere is almost always caused by light-scattering sulfate aerosols derived from large volcanic eruptions. Historical reports of a dimming of the Sun, red twilight glows, reddish solar haloes, and dark total eclipses of the Moon indicate a high turbidity; contrariwise, a ruddy disk shown by the eclipsed Moon betrays a clear stratosphere. On the basis of an extensive search of primary European and Middle Eastern written sources pertaining to the ancient and early medieval periods, seven stratospheric dry fogs, in addition to the four major ones already known, have been identified by using solar observations, and five smaller ones have been detected from dark total lunar eclipses. Seven of the eight most important dry fogs between 300 B.C. and A.D. 1000 can be either definitely or plausibly correlated with high levels of sulfate acidity observed in Greenland ice cores. An important conclusion is that this sample is probably very nearly complete for major dry fogs during this period. A second conclusion is that the ratio of dark to normal total lunar eclipses during early medieval times (A.D. 400–1000) appears to be equal, approximately, to the ratio that has prevailed for the past 40 years. These conclusions suggest that the frequency of volcanic eruptions, both large and moderate, throughout the world may have remained statistically constant (on a long timescale) since at least 300 B.C. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0370 Atmospheric Composition and Structure: Volcanic effects (8409); 1704 History of Geophysics: Atmospheric sciences; 1749 History of Geophysics: Volcanology, geochemistry, and petrology; *KEYWORDS:* aerosol, historical sources, ice cores, lunar eclipses, solar observations, stratosphere

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## 1. Introduction

[2] The stratosphere was recognized and named in 1900 in the course of a series of in situ balloon measurements [*Goody*, 1954]. Some of its properties, however, had already been discovered visually from the ground by investigation of the atmospheric aftereffects of the great eruption of Krakatau Volcano in 1883 [*Symons*, 1888]. Since modern studies of volcanic eruptions since 1900 have confirmed the validity of these remote ground-based observations [*Stothers*, 1996], similar reports made in even earlier times can now be safely used to infer past periods of notable volcanic disturbances to the stratosphere.

[3] What, specifically, are the visible atmospheric effects that explosive volcanic eruptions produce? Most readily noticed are (1) a reddening and a dimming of the Sun and other stars; (2) red or purple twilight glows; (3) reddish haloes (Bishop's rings) around the Sun; and (4) dark total eclipses of the Moon. These phenomena are all caused by the scattering of incident sunlight (or starlight) by sulfuric acid aerosols in the stratosphere. Volcanoes inject into the stratosphere the primary gas $SO_2$, which combines with $H_2O$ in a series of heterogeneous reactions to form $H_2SO_4$ aerosols. Stratospheric winds then distribute the aerosols around the hemisphere or, in the case of tropical eruptions, around the globe. The aerosols may reside in the stratosphere for up to 2–4 years depending on the altitude of injection. In the case of effusive or fissure-type eruptions, most of the $SO_2$ may never reach the stratosphere. In that case, the lifetime of sulfuric acid aerosols in the tropospheric layers of the atmosphere would not exceed a few days. On the other hand, large fissure eruptions often last for months, and therefore the local troposphere may remain polluted with aerosols for up to half a year and sometimes longer. For such eruptions, the chief atmospheric effects are a reddening and a dimming of the Sun and other stars. In all cases, the stratospheric and tropospheric aerosols are said to constitute a dry fog.

[4] A few noteworthy dry fogs from early volcanic eruptions have recently become the subject of detailed investigation. These include dry fogs due to Tambora (1815), Laki (1783), Eldgjá (934), and unidentified volcanoes in A.D. 1258, 626, and 536, and in 44 B.C. (see the review by *Stothers* [1999], and references therein). To


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extend the existing investigation to lesser dry fogs that occurred before A.D. 1000, a more intensive study of published historical documents has been undertaken, looking now at more than just the years when an eruption was already known from independent evidence found in ice cores and tree rings. The geographic areas included are all of Europe and the Middle East, and the methods of study follow those that were used before for the eruptions of 44 B.C. and A.D. 536 and 626 [*Stothers and Rampino*, 1983a].

[5] An important additional body of literature from the Middle East has now become available in English translation, namely, cuneiform texts written between the eighth century and the first century B.C. [*Hunger and Pingree*, 1999]. These texts include astronomical and meteorological diaries that provide almost day-to-day observational data for the core period from the fourth century to 61 B.C., as recorded at Babylon.

[6] Another geographic area providing potentially useful texts is the Far East, especially China [*Yau and Stephenson*, 1988; *Pang*, 1991]. Although researchers have by no means exhaustively searched the extant Far Eastern literature, the results have been slender. Reports of observations of solar and stellar dimming have turned up only for the eruptions of 44 B.C. and A.D. 536. Furthermore, most reports of lunar eclipses in the ancient Chinese literature appear to refer to theoretically calculated eclipses [*Schove*, 1984].

[7] *Scuderi* [1990a] has attempted to use Chinese reports of prolonged sunspot visibility and of "black vapors" seen near the Sun to infer the presence of volcanic aerosol veils. He finds a statistically significant correlation of these sightings with the times of reduced northern hemisphere temperatures as deduced from narrow annual tree ring widths, such as might be expected to occur in the aftermath of a large volcanic eruption. On the other hand, his results can be only statistically valid in view of the ambiguity of the Chinese reports, whereas we are here interested in specific definite cases. Moreover, reports of sightings of this kind have not been associated with volcanic eruptions in more recent centuries.

[8] Generally speaking, our scientific information about early volcanic aerosol veils comes from Europe and the Middle East. For the centuries before A.D. 1000, the data are very spotty, being dependent on the vagaries of manuscript survivals and on what was deemed by ancient and medieval writers to be worthy of reporting. In addition, due to frequent corruptions in text transmission, later compilations must be used as sparingly and as cautiously as possible; contemporary writings are much to be preferred whenever available. Probably all dry fogs from the greatest eruptions since 600 B.C. have been mentioned in the extant literature, as has been surmised from a direct comparison of the written record [*Stothers and Rampino*, 1983b] with the glaciochemical record of sulfate acidity in the annual layers of dated polar ice cores [*Hammer et al.*, 1980]. For the smaller eruptions that are less than Tambora-class, completeness is obviously impossible despite our making a comprehensive search of the extant literature. We shall find, however, that the threshold of dry fog detection using solar observations reported in available documents is approximately the same as the threshold using polar ice cores as estimated by *Robock and Free* [1996] and *Clausen et al.* [1997]. With lunar eclipse observations we can do even better.

[9] Ancient and medieval authors and (where necessary to avoid ambiguity) the titles of their works will be cited here directly in the text. Modern compendia of some of their works are referred to by using the following abbreviations: Bollandists, Bollandist Fathers' *Acta Sanctorum*; Bouquet, Bouquet's *Recueil des Historiens des Gaules et de la France*; *CSBH*, *Corpus Scriptorum Byzantinae Historiae*, Bonn Series; *MGHAA, Monumenta Germaniae Historica Auctores Antiquissimi*; *MGHSRM, Monumenta Germaniae Historica Scriptores Rerum Merovingicarum*; *MGHSS, Monumenta Germaniae Historica Scriptores*; *PG*, Migne's *Patrologia Graeca*; *PL*, Migne's *Patrologia Latina*; *RIS*, Muratori's *Rerum Italicarum Scriptores*.

[10] In section 2 we present the evidence for dry fogs based on observations of the Sun and other stars, as well as on reports of red twilight skies and other phenomena. Section 3 contains the evidence using dark total eclipses of the Moon, along with known observations of normal lunar eclipses. A simple statistical analysis and a summary of our results conclude the paper in section 4.

## 2. Solar Observations

[11] Dry fogs can be difficult to differentiate from more familiar meteorological phenomena that dim the Sun and other stars unless adequate information is available concerning the duration of the observing haze, the unusual twilight coloration, and the reddish haloes seen around the Sun. Even if some doubt persists in ambiguous cases, one can often rely on glaciochemical evidence of elevated sulfate acidity in dated polar ice cores. Caution, however, is necessary in the case of older eruptions, because published ice core dates for sulfate acidity signals before A.D. 1000 are not wholly reliable and the dating error increases with age.

[12] Ancient and medieval documentary sources have been extensively surveyed by the present author for the period before A.D. 1000 and by *Schove* [1984], with the collaboration of A. Fletcher, for the period A.D. 1 to 1000. At and around the dates of the major ice core sulfate acidity peaks and the dates of all known large volcanic eruptions (necessarily Mediterranean eruptions), the present search has been conducted more thoroughly. Nevertheless, the intent has been to be complete in all periods. In the second edition of the compilation *Volcanoes of the World* [*Simkin and Siebert*, 1994], there remain so many erroneous eruption dates that the original source catalogs have been consulted instead; for the ancient period, we have used *Stothers and Rampino* [1983a] and for the medieval period, *Alfano* [1924], *Reck* [1936], and *Tanguy* [1981]. Our results now follow.

### 2.1. Seventeenth or Sixteenth Century B.C.

[13] Fiery red sky glares [*Hunger*, 1992; *Foster et al.*, 1996] and an eleven-month invisibility of Venus [*Reiner and Pingree*, 1975; *Baillie*, 1995] seem to have occurred at least once very early in Mesopotamian history, as did a period of dimmed sunlight in very early Chinese history

[*Pang et al.*, 1989]. Some of these undated phenomena may be associated with the Bronze Age eruption of Thera (Santorini), as *Foster et al.* [1996], *Baillie* [1995], and *Pang et al.* [1989] have speculated. For this great eruption, historical information [*Foster et al.*, 1996] favors the sixteenth century, whereas tree ring data [*Baillie*, 1999; *Manning et al.*, 2001] and ice core data [*Hammer et al.*, 1987; *Zielinski et al.*, 1994; *Clausen et al.*, 1997] suggest the seventeenth century. The undated sky phenomena are useless for fixing the date.

### 2.2. Sixth Century B.C.

[14] There was an "eclipse" of the Sun that lasted a whole month, according to Xenophanes (pseudo-Plutarch, *Epitome* 2.24; Stobaeus, *Eclogae* 1.25). Since Xenophanes (sixth century B.C.) displays a special scientific interest in solar eclipses [*Bicknell*, 1967], his testimony is highly credible. A prolonged dimming of the Sun's light could have been due to a volcanic aerosol veil.

### 2.3. 217 B.C.

[15] The Sun's disk seemed to be diminished, and the Sun appeared to be struggling with the Moon (Livy 22.1.9–10). It is very unlikely that this solar darkening in central Italy arose from an eruption of Vesuvius, as was once suggested [*Stothers and Rampino*, 1983a, 1983b]. Most of the available literary and volcanological evidence runs counter to such a proposal [*Rosi et al.*, 1987; *Forsyth*, 1990a; *Rolandi et al.*, 1998]. A partial solar eclipse on 11 February 217 B.C., however, would have been visible over central Italy [*von Oppolzer*, 1887; *Ginzel*, 1899].

### 2.4. 212–200 B.C.

[16] The Sun seemed to be redder than usual, like the color of blood, in 212, and appeared red throughout the day when skies were clear, in 200, as seen from parts of central Italy (Livy 25.7.8., 31.12.5). *Forsyth* [1990b] has previously pointed out the Italian report of a halo-corona complex around the Sun in 203 (Livy 30.2.12). Babylonian observers, too, reported a halo around the Sun in 203, but such reports are very common there [*Sachs and Hunger*, 1989]. For three months during the year 208, stars were invisible from northern China [*Pang et al.*, 1987]. In addition, there was a pronounced cooling at high latitudes during the years 208–204, as indicated by northern tree ring data [*Baillie and Munro*, 1988; *Baillie*, 1995]. All of these phenomena can be invoked as evidence for a recurrent or a prolonged volcanic dry fog, just as *Hammer et al.* [1980] first proposed on the basis of a strong acidity peak in the Camp Century, Greenland ice core, dated at 210 ± 30. However, other Greenland ice cores, although better dated, do not show such a peak, or at least a strong one [*Zielinski et al.*, 1994; *Clausen et al.*, 1997]. Perhaps the eruptions were only of modest size. The historical data seem to suggest that at least two eruptions occurred between 212 and 200.

### 2.5. 145–144 B.C.

[17] Redness occurred repeatedly in the eastern and western skies over Babylon during September–October 145 and during July–August 144 [*Sachs and Hunger*, 1996]. This is the only report of such a persistent red sky phenomenon in the nearly continuous record of well-dated astronomical and meteorological events reported at Babylon during the last four centuries B.C. [*Sachs and Hunger*, 1988, 1989, 1996]. The redness seen in 145 and 144 was most likely due to a volcanic dry fog. Although no obvious reference to it appears in Greco-Roman literature, this period is very poorly documented in Western sources. A moderate acidity peak in a Greenland ice core crops up at around 147–149 [*Zielinski et al.*, 1994; *Clausen et al.*, 1997], a date which could well be off by a few years.

### 2.6. 122–121 B.C.

[18] A sky bow (presumably seen at Rome) surrounded the Sun in 121 (Pliny the Elder 2.98). Mount Etna erupted in 122, and if Obsequens's (32) reported reach of the ashfallout as far as Catania can be used as valid evidence, this was possibly the largest Etnan eruption during classical antiquity before 44 B.C. [*Stothers and Rampino*, 1983a]. Concerning the sky bow, although its color is unknown, see our remark below about 90 B.C.

### 2.7. 90 B.C.

[19] A red ring surrounded the Sun (Pliny the Elder 2.98). This isolated report is mentioned only because the unusual halo color, red, suggests Bishop's ring, an indicator of stratospheric dry fog.

### 2.8. 44–42 B.C.

[20] Many manifestations of dry fog appeared both in Italy [*Stothers and Rampino*, 1983a; *Rampino et al.*, 1988] and in northern China [*Schove*, 1951; *Pang et al.*, 1986; *Pang*, 1991]. The most intense phase of the dry fog probably lasted 9–10 months during the year 44. Long assumed to be due to ordinary cloudiness [*Ginzel*, 1899; *Boll*, 1909], the darkened skies were first associated with the eruption of Mount Etna in 44 B.C. by *Hammer et al.* [1980]. The volcano connection has been pursued by many others since then [*Forsyth*, 1988; *Scuderi*, 1990a; *Bicknell*, 1993; *Baillie*, 1995; *Ramsey and Licht*, 1997]. Greenland ice cores show greatly elevated acidities in layers that have been dated between 54 and 40 B.C. [*Hammer et al.*, 1980; *Herron*, 1982; *Hammer*, 1984; *Johnsen et al.*, 1992; *Zielinski et al.*, 1994; *Zielinski*, 1995; *Clausen et al.*, 1997]. *Zielinski* [1995] found, specifically, two acidity peaks at 53 ± 2 and 43 ± 2 B.C., the older one arising from perhaps a very high-latitude eruption and the younger one from Etna. A supposed eruption of Etna in 50–49 (Lucan 1.545–548; Petronius 122.135–136) seems now to have been a literary transfer of the 44 eruption reported by Vergil (see the scholia to Lucan 1.543–547) [*Rampino et al.*, 1988; *Mynors*, 1990, p. 92].

### 2.9. A.D. 14

[21] The Sun as a whole was "eclipsed" (Cassius Dio 56.29.3; Eusebius, *Chronicle*, Olymp. 198; Dexter, *Chronicle*, Migne, *PL*, *31*, 66). Since there was no true eclipse of the Sun in the year 14 [*von Oppolzer*, 1887], this report might refer to a dry fog. On the other hand, Augustus Caesar died in 14, and according to Dio, the solar darkening was an omen of his death. So it could

have been just a meteorological darkening (a parallel would be the Crucifixion darkness reported in the New Testament). *Schove* [1984], however, regarded the darkening as a misdated record of the partial solar eclipse of 15 February A.D. 17.

### 2.10. A.D. 536–537

[22] A dry fog lasting 12–18 months covered the Mediterranean area and probably also the Middle East [*Stothers and Rampino*, 1983a; *Stothers*, 1984; *Rampino et al.*, 1988]; possibly it even reached northern China [Pang and Chou in the work by *Weisburd*, 1985]. The climatic and social repercussions of this event have formed the subject of four recent books [*Baillie*, 1999; *Keys*, 1999; *Gill*, 2000; *Gunn*, 2000] as well as many research papers. The source volcano is unknown, although Rabaul, Papua New Guinea [*Stothers*, 1984], some unidentified high-latitude volcano [*Stothers*, 1999], Krakatau, Indonesia [*Keys*, 1999], and El Chichón, Mexico [*Gill*, 2000] have all been suggested. Dates of elevated acidity in Greenland ice cores scatter between 516 and 540 [*Hammer et al.*, 1980; *Herron*, 1982; *Hammer*, 1984; *Zielinski*, 1995; *Clausen et al.*, 1997]. Although a meteoritic source of the dry fog has been proposed [*Clube and Napier*, 1991; *Baillie*, 1994], the volcano hypothesis seems to be more plausible on both glaciochemical and historical grounds [*Stothers*, 1999].

### 2.11. A.D. 626–627

[23] The Sun was dimmed for 8–9 months over the eastern Mediterranean and, apparently, over Ireland [*Stothers and Rampino*, 1983a]. This was doubtless due to a volcanic dry fog. The year is somewhat uncertain. Syriac chroniclers writing in the early eighth century give 627 as the date of two (nonexistent) "eclipses" of the Sun and Moon (James of Edessa, *Chronicle*, p. 250, Brooks; *Chronicle to A.D. 724*, p. 113, Chabot), while Syriac writers of the tenth to thirteenth centuries provide the year 626 together with a more detailed description of the solar darkening (Agapius, *Universal History*, p. 452, Vasiliev; Michael the Syrian, *Chronicle* 11.409, Chabot; Bar-Hebraeus, *Chronography* 10.96, Budge; *Chronicle to A.D. 1234*, p. 181, Chabot). Various Irish chroniclers mention a darkness in 624, a year that becomes 625 after applying a needed chronological correction [*Schove*, 1984]. A date of 625 would harmonize with a reliable Japanese climatic report that unusually cold and rainy weather broke out in Japan during the summer of 626 (two years before the reported total solar eclipse of 10 April 628) (*Nihongi* 22.39–40, Aston). This accounting of the available evidence would clear up the confused discussions of *Newton* [1972] and *Schove* [1984], which implied several solar darknesses occurring in the period 617–629. Greenland ice cores show elevated levels of acidity at years placed variously in the range 622–640 [*Hammer et al.*, 1980; *Hammer*, 1984; *Zielinski et al.*, 1994; *Zielinski*, 1995; *Clausen et al.*, 1997].

### 2.12. A.D. 744

[24] The Sun became dim and blood-colored, the atmosphere misty and dark, for five or six days in August (Theophanes Confessor, *Chronography*, Migne, *PG*, *108*, 849; Anastasius, *History*, Migne, *PG*, *108*, 1373; Agapius, *Universal History*, p. 520, Vasiliev; George Cedrenus, *Histories*, Migne, *PG*, *121*, 885; *Historia Miscella*, Muratori, *RIS*, *1*(1), 156). This event was reported from the Middle East, and the year is now quite securely established [*Mango and Scott*, 1997]. In the same year, northwestern Germany experienced a strange fall of ash (*Annals of Xanten, MGHSS*, *2*, 221), which ought not to be confused with a Middle Eastern dust storm that occurred in the spring of 742. If the ashfall and the dim Sun are associated, they suggest a volcanic eruption in Iceland with strong northwesterly winds blowing. Greenland ice cores show an acidity signal in 743 or 744, but this signal is fairly weak, perhaps owing to the unfavorable wind direction [*Hammer et al.*, 1980; *Clausen et al.*, 1997].

### 2.13. A.D. 797–798

[25] The Sun was darkened for 17 days in A.D. 797 and did not cast its rays, with the result that ships at sea went off course (Theophanes Confessor, *Chronography*, Migne, *PG*, *108*, 952; George the Monk, *Chronology*, Migne, *PG*, *110*, 968; Anastasius, *History*, Migne, *PG*, *108*, 1405–1406; George Cedrenus, *Histories*, Migne, *PG*, *121*, 909; Leo Grammaticus, *Chronography*, Bonn, *CSBH*, *47*, 199; *Historia Miscella*, Muratori, *RIS*, *1* (1), 170; Michael Glycas, *Annals*, Migne, *PG*, *158*, 532). Theophanes was probably the original source for all the later Byzantine and Italian chroniclers. French chroniclers, some of them contemporary with Theophanes, and also later German chroniclers, have recorded that the sidus Martis (the southern constellation Scorpius [*Allen*, 1963]) could not be seen from July 797 to the following July (*Annales Tiliani*, Bouquet, *5*, 23, *Annales Loiseliani*, Bouquet, *5*, 320; *Annals of Lorsch*, *MGHSS*, *1*, 184; Ado of Vienne, *Chronicle*, Bouquet, *5*, 320; Regino of Prüm, *Chronicle, MGHSS*, *1*, 562). Since at the latitudes of France the first-magnitude star $\alpha$ Scorpii culminates low near the horizon on 11 July, a total zenithal optical depth of $\sim$1 would suffice to produce the minimally needed 4 magnitudes of extinction. From Theophanes's account of solar darkening, *Newton* [1972] and *Schove* [1984] have inferred a volcanic aerosol veil. This is supported by the Crête, Greenland, ice core (although not by any others), in which the largest acidity peak between the years 626 and 934 falls in the year 798 ± 2 [*Hammer et al.*, 1980]. Therefore, this eruption may have been important enough to cause climatic cooling. The *Annals of Ulster* (A.D. 798) mentions a "great snow" in 798, while northern tree ring data indicate very cool summers in the period 794–800 [*Briffa et al.*, 1990; *Scuderi*, 1990b, 1993]. Observation and mention of the odd fact about stellar extinction doubtless reflects France's reawakened interest in astronomy during the brief period of the Carolingian Renaissance. The very large extinction over Europe suggests a local (perhaps Icelandic) eruption.

### 2.14. A.D. 897

[26] Red skies in Egypt made the outdoor surroundings appear red (Eutychius of Alexandria, *Annals*, Migne, *PG*, *111*, 1144; al-Tabari, *Annals*, A.H. 284; Elias of Nisibis, *Chronicle*, p. 92, Brooks). This event, which occurred only on 5 May and only near Alexandria, was apparently

caused by a red sandstorm, as mentioned by the chroniclers. It is extremely unlikely to be related to the moderate acidity peak seen in Greenland ice cores somewhere in the years 898–903 [*Hammer et al.*, 1980; *Zielinski et al.*, 1994; *Zielinski*, 1995; *Clausen et al.*, 1997]. Similarly, a violent storm accompanying an earthquake in Egypt seems to have created a red Sun on 13 May 963 (al-Antaki, quoted by *Guidoboni* [1994, p. 398]). Redness of the northeastern sky at some time in 977 or 978 (Ibn al-Athir, quoted by *Guidoboni* [1994, p. 401]) may have been due to another sandstorm or else to an auroral display.

### 2.15. A.D. 934

[27] A dry fog is strongly indicated by a day-long red appearance of the Sun over Germany and Ireland [*Stothers*, 1998]. *Schove* [1984] has noted four other mentions of the red Sun in very late European chronicles, all of which have referred the event to the reign of Lothair II (931–950) in Italy. The assigned dates in these chronicles range from 937 to 963, but these are undoubtedly errors for 934, the date implied, somewhat approximately, by our main source, the contemporary chronicler Widukind of Corvey in Saxony. The volcano Eldgjá in Iceland erupted around this time, probably starting during the summer months. Greenland ice cores place the eruption date somewhere in the interval 934–938 [*Hammer et al.*, 1980; *Herron*, 1982; *Hammer*, 1984; *Johnsen et al.*, 1992; *Zielinski et al.*, 1994, 1995; *Zielinski*, 1995; *Clausen et al.*, 1997]. Although northern tree ring signals around this date are sparse [*D'Arrigo et al.*, 2001], the documentary evidence is abundant and quite explicit about the atmospheric cooling (see also the contemporary Persian chronicler Hamza al-Isfahani, *Annals* 10.7, Gottwaldt). Climatic and historic evidence together tie the starting date to 934. The eruption itself was of fissure type and was apparently drawn out over several years [*Thordarson et al.*, 2001].

## 3. Lunar Eclipse Observations

[28] During a total or partial eclipse of the Moon, the Sun's rays are refracted, and to a lesser extent scattered, into the shadow cone by particles in the Earth's upper atmosphere. The bending of the Sun's light bathes the lunar surface with mostly longer wavelengths, endowing it with a reddish or coppery color. If the upper troposphere is filled with clouds or if the stratosphere contains widespread volcanic aerosols, the Moon will appear dark or even disappear entirely. Partial cloudiness, however, will cause the Moon to exhibit a variety, and even a progression, of different colors [*Olivier*, 1966]. From time immemorial, the reddened face of the eclipsed Moon must have been obvious to the casual observer (e.g., Ovid, *Amores* 1.8), but the correct physical explanation of the redness and of the other colors persistently eluded the ancient and medieval experts in all cultures, including Mesopotamia [*Rochberg-Halton*, 1988], the Greco-Roman world (Plutarch, *On the Face in the Moon* 934; Ptolemy, *Tetrabiblos* 2.9; Hephaestion of Thebes 1.21.2), and the Arabic world (al-Biruni, *Coordinates* 168–169, Ali). Kepler in 1617 was the first author to give the correct explanation of the reddening, and Flammarion in 1884 explained the darkening after volcanic eruptions.

[29] Several catalogs of lunar eclipse reports in ancient and medieval literature have been prepared during the past five centuries. We have used here the four most recent catalogs; *Ginzel* [1899] and *Boll* [1909] for 900 B.C. to A.D. 600, *Newton* [1970, 1972] for 900 B.C. to A.D. 1000, and *Schove* [1984] for A.D. 1 to 1000. In all cases, the original literature has been freshly consulted in order to evaluate the accuracy and context of all the reports. Identifications of particular eclipses have been accepted from either Boll or Schove with only minor exceptions. We cite months and days from *von Oppolzer*'s [1887] catalog of calculated eclipses. Lunar eclipses are not rare in nature, and observable total lunar eclipses occur about once a year on the average [*Keen*, 1983], but they are not often reported in the early literature.

[30] It is insufficient to know that an eclipse has been reported in order to use that eclipse. One must also determine whether it was an observed eclipse or merely a calculated eclipse. If a color was reported, was it an actual observation or just a stock color description? In view of the fact that an eclipse color is rarely mentioned by any early chronicler and, if one is, the chronicler in most cases was a contemporary of the event, we can usually regard the color as an actual observation rather than a mere synonym for the word "eclipsed", unless there is evidence to the contrary. If no color at all is mentioned as is usually the case, we shall ignore the eclipse, even though one might be tempted to assume that this was a normal, reddish eclipse. Probably in nearly all cases it was, but our purpose is to present actual known data about the color, which can then reveal with some certainty the state of stratospheric transparency.

### 3.1. Dark Lunar Eclipses

#### 3.1.1. 21 June 168 B.C.

[31] The moon grew black, lost its light, turned all sorts of colors, and then disappeared (Plutarch, *Aemilius Paulus* 17.7–8). No other ancient author who mentions this eclipse, including the contemporary Polybius, provides these details (Polybius 29.16; Cicero, *On the Republic* 1.23; Livy 44.37; Justin-Trogus 33.1; Valerius Maximus 8.11.1; Pliny the Elder 2.53; Quintilian 1.10.47; Frontinus, *Stratagems* 1.12.8; Cassius Dio in Zonaras 9.23; Julius Paris 8.11.1). Plutarch's (circa A.D. 100) account, however, does accurately describe a total lunar eclipse. The umbra appears quite black (by contrast) when it first encroaches on the Moon [*Russell et al.*, 1945]. As the moonlight begins to fade, a succession of lunar colors make their appearance if the Earth's limb is partly clouded, causing sunlight to be refracted from different layers of the atmosphere [*Olivier*, 1966]. Plutarch's report of the Moon's subsequent disappearance suggests that rotation of the Earth eventually brought a more extensively clouded area to the limb. Alternatively, rising clouds might have blocked the viewer's line of sight, as happened at the total lunar eclipse of 27 September A.D. 14 (Tacitus, *Annals* 1.28; Cassius Dio 57.4.4). Whether Plutarch's report of the Moon's final disappearance implies a truly dark eclipse is, therefore, at best questionable [*Bicknell*, 1968, 1983; *Stothers*, 1986]. Although it is possible that Plutarch is simply quoting

astrological tradition concerning the expected colors of lunar eclipses [*Fotheringham*, 1921; *Stothers*, 1986], he may well have gotten an actual account from a book by the astronomer Sulpicius Gallus, who witnessed the eclipse and then wrote a book about eclipses (Pliny the Elder 1.2, 2.53). The issue remains undecided.

**3.1.2. 63–44 B.C.**

[32] The eclipsed Moon appeared to vanish on several occasions (Lucretius 5.751; Cicero, *On Divination* 1.18, 2.17). *Bicknell* [1983, 1987] has argued that both Lucretius and Cicero witnessed and described a number of dark total lunar eclipses during their lifetimes. He also has speculated that the sorceress Aglaonice, who reputedly could "draw down" the Moon, lived around this time and took clever advantage of those eclipses. Opposed to these views are arguments that Lucretius and Cicero in their poems were only indulging in stock descriptions and poetic phrases, and that Aglaonice, if not purely mythological, lived before the fifth century B.C. [*Stothers*, 1986, 1987]. There is no independent scientific evidence one way or the other in this case, but a long string of dark lunar eclipses is not attested in any other historical period.

**3.1.3. 19 November A.D. 560**

[33] The Moon was darkened and could hardly be seen (Marius of Avenches, *Chronicle, MGHAA*, *11*, 237). The chronicler Marius, a contemporary, probably witnessed this eclipse himself.

**3.1.4. 31 December A.D. 567**

[34] The Moon was not visible (*Excerpta Sangallensia, MGHAA*, *9*, 335). The St. Gall extracts were put together in the seventh century, but are reliable for events in the previous century [*Schove*, 1984].

**3.1.5. 11 December A.D. 577**

[35] The Moon frequently turned black in this year (Gregory of Tours, *History of the Franks*, Bouquet, *2*, 249). The partial eclipse of 11 December was the only lunar eclipse that occurred in 577 [*von Oppolzer*, 1887]. Although Gregory of Tours was a contemporary author, any physical significance of his term "black" can be strongly doubted in view of the similar language he used for the eclipse of 5 April 581, which likewise was only partial. More generally, Gregory always wrote on astronomical matters in exaggerated, and even naively miraculous, terms (*On Stars' Courses, MGHSRM*, *1*(2), 410, 413).

**3.1.6. 5 April A.D. 581**

[36] The Moon grew very dark (Gregory of Tours, *History of the Franks*, Bouquet, *2*, 257). Being partial, this was probably not a truly dark eclipse (see our remarks above about the eclipse of 11 December 577).

**3.1.7. 4 January A.D. 763**

[37] The moon appeared dark (*Annals of Ulster*, A.D. 761; Tigernach, *Annals*, p. 260, Stokes). Since the Moon during the eclipse of 13 December 726 was described by the *Annals of Ulster* (under A.D. 724) as being both dark and blood-colored, the mention here of only darkness is probably significant. Because early medieval dates listed in the Irish chronicles can often be in error by up to 4 years, there is no need to doubt the identification of this eclipse as given by *Schove* [1984]. The *Annals of Ulster* is composed of successive additions of text onto a core that was put together at an early date, and therefore it presents reliable (except for dates) contemporary information from about the middle of the sixth century. Since the color of a lunar eclipse is not always noted, a color when stated can be assumed to be a genuine observation.

**3.1.8. 4 December A.D. 773**

[38] The Moon appeared dark (*Annals of Ulster*, A.D. 772). This is probably a genuine observation (see our remarks above about the eclipse of 4 January 763).

**3.1.9. 30 March A.D. 861**

[39] The Moon turned black (*Annals of St. Bertin, MGHSS*, *1*, 454). Since the *Annals of St. Bertin* also records the eclipses of 18 April 832 and 5 December 838, but does not mention their color, the blackness described here is probably significant.

### 3.2. Reddish Lunar Eclipses

**3.2.1. 27 August 413 B.C.**

[40] The Moon lost its light and emitted all sorts of colors (Plutarch, *Nicias* 23.1–2). Since these color details are not mentioned by Thucydides (7.50), who was a contemporary, or by any other late author (Polybius 9.19; Diodorus Siculus 13.12.6; Pliny the Elder 2.54; Quintilian 1.10.47), Plutarch probably supplied them as a literary gloss. The context in which he mentions them has, in fact, a distinctly didactic tone, and he fails to mention them in an independent account of the same eclipse (*On Superstition* 169A). We have already had occasion to doubt the similar details given by him for the eclipse of 21 June 168 B.C.

**3.2.2. 20 September 331 B.C.**

[41] The Moon faded at first and then appeared blood-colored (Quintus Curtius 4.10.2). Almost certainly, Curtius (a rhetor writing in the first century A.D.) is inventing the color remark as no other author, not even Plutarch, records a color for this eclipse (Cicero, *On Divination* 1.121; Pliny the Elder 2.180; Plutarch, *Alexander* 31.4; Ptolemy, *Geography* 1.4; pseudo-Callisthenes 3.17; Julius Valerius 3.27; scholium to Aratus, p. 317, Maass). *Bicknell* [1983], however, accepts the color remark as a genuine observation, taken from Curtius's unknown source.

**3.2.3. 17 March 284 B.C.**

[42] The eclipse of the Moon was red [*Steele*, 2000, p. 42]. This was a total lunar eclipse [*von Oppolzer*, 1887].

**3.2.4. 1 August 226 B.C.**

[43] The eclipse of the Moon was red [*Sachs and Hunger*, 1989]. This was a total lunar eclipse [*von Oppolzer*, 1887].

**3.2.5. 4 October 183 B.C.**

[44] The eclipse of the Moon was red [*Sachs and Hunger*, 1989]. This was a partial lunar eclipse [*von Oppolzer*, 1887].

**3.2.6. 21 March 135 B.C.**

[45] The eclipse of the Moon was red [*Sachs and Hunger*, 1996]. This was a total lunar eclipse [*von Oppolzer*, 1887].

**3.2.7. 1 June 120 B.C.**

[46] The eclipse of the Moon was reddish [*Sachs and Hunger*, 1996]. This was a total lunar eclipse [*von Oppolzer*, 1887].

**3.2.8. 1 May 109 B.C.**

[47] The eclipse of the Moon was red-brown [*Sachs and Hunger*, 1996]. This was a partial lunar eclipse [*von Oppolzer*, 1887].

**3.2.9. 25 August 106 B.C.**

[48] The eclipse of the Moon was red [*Sachs and Hunger*, 1996]. This was a total lunar eclipse [*von Oppolzer*, 1887].

**3.2.10. 3 April A.D. 33**

[49] The Moon turned blood-colored and failed in its light (pseudo-Pilate, *Report of Pilate*). *Humphreys and Waddington* [1983] have tried to use this undated New Testament Apocryphal fragment, together with the apostle Peter's (Acts 2:20) mention of a prophecy by Joel (2:31) about the Moon's turning to blood, in order to bolster their case for a report of an actual lunar eclipse at the time of the Crucifixion. However, the *Report of Pilate* is almost universally regarded as a late Christian forgery, put together from standard New Testament material. The only possibly relevant lunar eclipse in the years around the uncertain time of the Crucifixion is 3 April 33. Since this partial eclipse was visible only at moonrise and had a negligible magnitude [*Schaefer*, 1990], the eclipse in the *Report of Pilate* can be regarded as fictitious.

**3.2.11. 18 October A.D. 69**

[50] The Moon appeared both blood-colored and black, and emitted still other terrifying colors (Cassius Dio 64.11). *Ginzel* [1899] and *Boll* [1909] have questioned Dio's account on the grounds that this eclipse was only a partial one [*von Oppolzer*, 1887]. In fact, Dio's description of it sounds purely literary and was perhaps taken from Plutarch's lost *Life of Vitellius*. Tacitus, a contemporary, does not mention the eclipse at all.

**3.2.12. 31 August A.D. 304**

[51] The Moon turned blood-colored (*Martyrdom of Felix*, 24 October, Bollandists). The date of the martyrdom, the identity of Felix, and the eclipse itself are all so highly questionable [*Schove*, 1984] that we may safely dismiss this report as pure hagiography (compare 3 April A.D. 33).

**3.2.13. 2 March A.D. 462**

[52] The Moon turned blood-colored (Hydatius, *Chronicle, MGHAA*, *11*, 32; Fredegar, *Chronicle, MGHSRM*, *2*, 77). This report seems to be based on an authentic observation, in view of the fact that Hydatius, a contemporary chronicler, mentions the lunar eclipse of 26 September 451 without giving a color.

**3.2.14. 10 November A.D. 672**

[53] The Moon turned blood-colored (*Annals of Clonmacnoise*, A.D. 670; *Annals of Ulster*, A.D. 673; *Chronicum Scotorum*, A.D. 670; Tigernach, *Annals*, p. 203, Stokes). This color detail, like others in the Irish chronicles, can be regarded as genuine.

**3.2.15. 16 April A.D. 683**

[54] The face of the Moon was blood-colored (Anastasius, *Lives of the Popes*, Migne, *PL*, *128*, 849–850). Although Anastasius (the Vatican librarian) was a ninth-century author, his report is probably reliable since he does not give such a color detail for the lunar eclipse of 17 June 680.

**3.2.16. 11 November A.D. 691**

[55] The moon turned blood-colored (*Annals of Clonmacnoise*, A.D. 687; *Annals of Ulster*, A.D. 691; *Chronicum Scotorum*, A.D. 688; Tigernach, *Annals*, p. 212, Stokes). Several Welsh and Danish chronicles apparently refer to the same eclipse, possibly relying on the Irish accounts [*Schove*, 1984]. The eclipse was only a partial one [*von Oppolzer*, 1887].

**3.2.17. 13 January A.D. 716**

[56] The Moon appeared blood-red (Anastasius, *Lives of the Popes*, Migne, *PL*, *128*, 975–976). Note that Anastasius mentions the Moon's color for this eclipse as well as for the eclipse of 16 April 683, but not for that of 17 June 680. The color remark is believable.

**3.2.18. 13 December A.D. 726**

[57] The Moon was dark and blood-colored (*Annals of Ulster*, A.D. 724).

**3.2.19. 24 January A.D. 734**

[58] The Moon was blood-colored and then black (Continuator of Bede, *Chronicle*, Migne, *PL*, *95*, 290). The word "black" probably refers to the edge of the umbra during the time of egress.

**3.2.20. 24 January A.D. 753**

[59] The Moon was blood-colored (*Annals of Clonmacnoise*, A.D. 749; Tigernach, *Annals*, p. 254, Stokes). The continuator of Bede (*Chronicle*, Migne, *PL*, *95*, 292) says that the Moon was eclipsed by "a very black shield". Although this eclipse was only partial [*von Oppolzer*, 1887], the umbra would undoubtedly appear dark by contrast with the brighter parts of the Moon's disk.

**3.2.21. 23 November A.D. 755**

[60] The Moon appeared blood-red (Simeon of Durham, *History of the Kings*, A.D. 755). The color remark seems to be authentic, in view of the absence of such a detail given in Simeon's notices of the eclipses of 31 July 752 and 28 March 796. Although Simeon wrote in the twelfth century, his sources were reliable for this period (see our remarks above about the eclipse of 4 January 763).

**3.2.22. 26 February A.D. 788**

[61] The Moon was blood-red (*Annals of Ulster*, A.D. 787).

**3.2.23. 26 February A.D. 807**

[62] The Moon turned blood-colored (*Annals of Ulster*, A.D. 806; *Chronicum Scotorum*, A.D. 807).

**3.2.24. 1 April A.D. 926**

[63] The Moon paled and then turned blood-colored (Flodoard of Reims, *Annals, MGHSS*, *3*, 376). This report and all those that follow were made by continental European chroniclers who most likely were eyewitnesses.

**3.2.25. 4 September A.D. 936**

[64] The Moon appeared blood-colored and illuminated the night very little (Flodoard of Reims, *Annals, MGHSS*, *3*, 383). The faintness of this eclipse is probably attributable to lingering stratospheric aerosols after the massive Eldgjá eruption of 934.

**3.2.26. 4 September A.D. 955**

[65] The Moon turned blood-colored (Fleury chronicler, *History of the Franks*, Bouquet, *8*, 299; *Annals of Fleury*, Bouquet, *8*, 254).

**3.2.27. 15 August A.D. 965**

[66] The Moon turned blood-colored (*Annals of Prüm, MGHSS*, *15(2)*, 1292).

**3.2.28. 14 July A.D. 995**

[67] The Moon turned blood-colored (*Annals of Augsburg, MGHSS*, *3*, 124).

**3.2.29. 6 November A.D. 998**

[68] The Moon turned blood-colored (*Annals of Regensburg, MGHSS*, *17*, 584; *30*(2), 746).

## 4. Discussion

[69] The present study of primary written sources for the historical period before A.D. 1000 has turned up a number

of lesser stratospheric dry fogs in addition to the four prominent ones already known. To 44 B.C. and A.D. 536, 626, and 934, we can now add, with some confidence: 212–200 and 145 B.C. and A.D. 744 and 797; also, with rather less confidence, an unidentified year in the sixth century B.C. and, perhaps, 121 and 90 B.C. Mount Etna in Sicily gave birth to the two dry fogs of 121 and 44 B.C., while Iceland's Eldgjá produced the A.D. 934 northern haze. All of these dry fogs have been detected from either direct or indirect observations of the Sun. To these dry fogs can be added five other good cases, inferred from the reported darkness of total lunar eclipses in A.D. 560, 567, 763, 773, and 861. Although it is not certain whether stratospheric aerosols or cloudy tropospheric meteorological conditions were responsible for the eclipse darkness, modern experience suggests that stratospheric aerosols nearly always dominate the picture [*Keen*, 1983, 2001].

[70] Within the interval 300 B.C. to A.D. 1000, the presently detected dry fogs are distributed more or less randomly, giving us some confidence about the near completeness of our sample for intense dry fogs. This belief is supported by the evidence of measured high acidities in Greenland ice cores at or near the corresponding dry fog dates. In contrast, the distribution of total lunar eclipses with reliably reported colors is greatly skewed toward the period after A.D. 400. This asymmetry arises in large measure from the paucity of ancient Greco-Roman eclipse reports, since eclipses in that culture tended to be mentioned only in association with important historical events and then were embellished with rhetorical textbook descriptions [*Fotheringham*, 1921]. A unique exception is the cluster of notices about reddened lunar disks in 284, 226, 183, 135, 120, 109, and 106 B.C. reported from Babylon. It is clear that these seven eclipses do not support *Bicknell*'s [1983] conjecture, based on insufficient Greco-Roman sources, that dark total lunar eclipses might have been common between 168 and 44 B.C.

[71] Assuming that lunar eclipse colors have been randomly chronicled during the period A.D. 400–1000, we may estimate the ratio R of dark to normal lunar eclipses from our presently compiled numbers of such eclipses. We thus obtain R = 5/15 = 0.33. To compare this result with modern total lunar eclipses, we use *Keen*'s [1983, 2001] tabulation of 38 eclipses observed during the years 1960–2001, for which he has derived stratospheric visual optical depths, $\tau_{vis}$. For the preceding years 1881–1959, we use *von Oppolzer*'s [1887] list of total lunar eclipses, together with our pyrheliometrically derived values of $\tau_{vis}$ [*Stothers*, 1996]. Over the whole interval 1881–2001, the smallest value of $\tau_{vis}$ for which naked-eye observers of the Moon have called the eclipse "dark" is 0.04 ± 0.02, based on the three eclipses of 16 October 1902 [*Link*, 1963], 15 September 1913 [*Link*, 1963], and 18 December 1964 [*Anonymous*, 1964, 1965]. Adopting, therefore, $\tau_{vis}$ = 0.04 as the dividing value between "dark" and "normal" eclipses, we find from *Keen*'s [2001] homogenous eclipse data the result R = 9/29 = 0.31. We thus conclude that the frequency and intensity of volcanic eruptions throughout the world during the early Middle Ages were close to what we have experienced in the course of the last 40 years. Although fluctuations in volcanic activity certainly took place over the past 16 centuries [e.g., *Stothers*, 1989, 1996], these seem to have operated on subcentury timescales.

[72] An optical depth of 0.04 implies a total aerosol mass of ~6 Tg contained in the global aerosol veil [*Stothers*, 1996]. By comparison, a glaciochemical analysis of ice cores is able to detect from background noise only an aerosol veil with a mass of ~30 Tg or greater [*Clausen et al.*, 1997]. Thus a Pinatubo-sized eruption would be barely detectable in polar ice cores. Although the advantage of the lunar eclipse method for dry fog detection is obvious, the downside of the method is that early historical reporting of lunar eclipses is very sporadic and is never detailed enough to yield anything but a lower limit on the aerosol mass.

[73] How well do our direct Mediterranean detections of the larger aerosol veils agree with detections of sulfate aerosols using ice cores from Greenland? *Hammer et al.* [1980] have analyzed the Crête ice core (which starts at A.D. 553) and have found six large acidity peaks before A.D. 1000; these occur at A.D. 623, 757, 798, 841, 934, and 971. Allowing for some dating uncertainty, three of these peaks correlate with historical dry fogs at 626, 797, and 934, while a slightly smaller acidity peak at 744 agrees with another historical dry fog of the same date. Thus, the historical method picks up about half of the largest events in the Crête ice core. From the work of *Clausen et al.* [1997], who have intercompared the Crête, Dye 3, and GRIP ice cores, it would seem that the smallest of the six large Crête acidity peaks lies near the threshold of distinguishability from background noise. The detailed comparisons of Dye 3 and GRIP ice cores have yielded nine significant sulfate peaks in the interval from 600 B.C. to A.D. 1000, namely at 244, 147, and 49 B.C., and at A.D. 516, 572, 757, 871, 898, and 934. Since four historical events at 145 and 44 B.C. and at A.D. 536 and 934 agree with dates from Clausen et al. within the possible errors, the historical method has again picked up about half of the largest ice core events. Last, *Zielinski et al.* [1994] have detected 29 sulfate peaks lying between 100 B.C. and A.D. 1000 in the GISP2 ice core. In view of the results of Clausen et al., it is unclear how many of these GISP2 sulfate peaks are truly significant, but the four largest occur at 53 B.C. and at A.D. 78, 640, and 939 [*Zielinski et al.*, 1994; *Zielinski*, 1995], with some uncertainty in the dating. The dry fog events at 44 B.C. and at A.D. 626 and 934, as well as the famous eruption of Vesuvius in A.D. 79, suggest that the strongest GISP2 signals can possibly all be accounted for by the historical data.

[74] It remains undetermined how many of the lesser of these Greenland signals are only noise spikes. This problem and the equally serious problem of accuracy in ice core dating have been discussed in detail by *Robock and Free* [1995], without any resolution at present. Another problem is the exaggerated signal produced by local volcanoes. This bias affects both the ice core method (Icelandic and Alaskan volcanoes) and the historical method (Mediterranean and Icelandic volcanoes). Local wind transports, however, can moderate or exacerbate the bias. Although the historical method is not as prone to contamination by false events, it is not wholly immune to them. All in all, present evidence suggests that the thresholds for detectability of large volcanic eruptions during the period under consideration

**Table 1.** Phenomena Indicating the State of Stratospheric Transparency, 600 B.C. to A.D. 1000

| Sun-Related Phenomena | Dark Total Lunar Eclipse | Reddish Lunar Eclipse | Reddish Lunar Eclipse |
|---|---|---|---|
| Sixth century B.C. | (168) B.C. | (413) B.C. | A.D. 691 |
| (217) | (63–44) | (331) | 716 |
| 212–200 | A.D. 560 | 284 | 726 |
| 145–144 | 567 | 226 | 734 |
| 122–121 | (577) | 183 | 753 |
| (90) | (581) | 135 | 755 |
| 44–42 | 763 | 120 | 788 |
| A.D. (14) | 773 | 109 | 807 |
| 536–537 | 861 | 106 | 926 |
| 626–627 | | A.D. (33) | 936 |
| 744 | | (69) | 955 |
| 797–798 | | (304) | 965 |
| (897) | | 462 | 995 |
| 934 | | 672 | 998 |
| | | 683 | |

Dates inside parentheses indicate doubtful cases.

(especially since 300 B.C.) are roughly comparable for the ice core and historical methods. An exception exists if the eruption is directly observed and reported, or if the color of a contemporary lunar eclipse is observed and reported.

[75] Table 1 summarizes all of our observational data for the years from 600 B.C. to A.D. 1000 in which information on stratospheric transparency is available. Dates enclosed in parentheses indicate questionable entries, some of them almost certainly spurious cases. These uncertain entries are very few in number, however, especially after A.D. 400. An obvious conclusion is that it is possible to infer something definite and useful about stratospheric aerosol conditions in even the earliest years of the preinstrumental historical period.

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# Ancient Scientific Basis of the "Great Serpent" from Historical Evidence

*By Richard B. Stothers**

**ABSTRACT**

Zoological data and a growing mythology contributed to ancient Western knowledge about large serpents. Yet little modern attention has been paid to the sources, transmission, and receipt in the early Middle Ages of the ancients' information concerning "dragons" and "sea serpents." Real animals—primarily pythons and whales—lie behind the ancient stories. Other animals, conflations of different animals, simple misunderstandings, and willful exaggerations are found to account for the fanciful embellishments, but primitive myths played no significant role in this process during classical times. The expedition of Alexander the Great into India (327–325 B.C.) and the Bagradas River incident in North Africa (256 B.C.) had enormous repercussions on the development of serpent lore. Credible evidence is found for the presence of ancient populations of pythons living along the North African coast west of Egypt and along the coast of the Arabian Sea between the Indus River and the Strait of Hormuz—places where they no longer exist today. The maximum sizes of ancient pythons may have been greater than those of today's specimens.

ANCIENT LITERATURE AND ART are peppered with depictions of huge serpents of various kinds. Certain similarities among all these serpents, however, occur across many cultures, as modern scholarship has abundantly shown.[1] The great serpent is always a snake, terrestrial or aquatic, and it acts either beneficently or harmfully toward human

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[1] Joseph E. Fontenrose, *Python: A Study of Delphic Myth and Its Origins* (Berkeley: Univ. California Press, 1959); Peter Hogarth and Val Clery, *Dragons* (London: Allen Lane, 1979); Karl Shuker, *Dragons: A Natural History* (London: Arum, 1995); David E. Jones, *An Instinct for Dragons* (New York: Routledge, 2000); and Michel Meurger, *Histoire naturelle des dragons* (Rennes: Terre de Brume, 2001). These works, like most others, discuss mainly the mythological aspects of the ancient great serpents.

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beings. Three main sources of information during antiquity could have contributed to forming the medieval, and hence the modern, picture of the great serpent: primitive myths, ancient inferences drawn from fossils of prehistoric beasts, and ancient historical observations of rare snakes and other animals.

The earliest mythological literature, being nonscientific and difficult to treat scientifically, does not much concern us here. Nevertheless, the unknown (and probably unknowable) origin of the early serpent myths must have resided, to some extent, in actual observations of large snakes. (See Figure 1.) I will argue here that the primitive myths traveled a separate path—via poetry and art—into the Middle Ages, where they then gradually became confused and blended with the more scientific tradition. The very infrequently studied fossil evidence has recently been thoroughly surveyed and analyzed by Adrienne Mayor.[2] Curiously, there is little to show that remains of prehistoric animals led in any obvious way to the development of the concept of the great serpent during classical times, although they may have influenced the early myths. Nonetheless, people in ancient times occasionally stumbled upon, and speculated about, large fossils, typically interpreting them as evidence of former giants. Very long fossil bones, such as the backbones of whales, as well as odd-shaped fossil heads of animals could have been associated with great serpents, according to Mayor, although the evidence remains circumstantial. This then leaves the historical evidence, which is the subject of this essay. My intention here is to show what the factual Western evidence is, how the various ancient reports propagated through the

***Figure 1.*** *Sea serpent. Greek islands, chalcedony gem (fifth century B.C.). By permission of the Metropolitan Museum of Art, New York. Bequest of William Gedney Beatty, 1941. (41.160.437.)*

[2] Adrienne Mayor, *The First Fossil Hunters: Paleontology in Greek and Roman Times* (Princeton, N.J.: Princeton Univ. Press, 2000).

classical literature, and how this ancient legacy was received by early medieval scholars. Such a study should prove fruitful because it bears not only on the general history of zoology but also on current scientific and cultural studies of known and suspected large serpents. In our modern Western world, suspected large serpents are often associated, plausibly or not, with the ancients' terrestrial "dragons" and marine "sea serpents."

Modern scholarly studies of the relevant ancient literature are surprisingly sparse, considering the perennial popularity of the topic of dragons and sea serpents. Erich Pontoppidan in 1755 discussed a small number of references to possible sea monsters from the Bible and from the works of Diodorus Siculus, Pliny the Elder, and various writers on the Bagradas River serpent. In 1892 A. C. Oudemans briefly surveyed the same material, adding a few more references. Bernard Heuvelmans in 1968 focused on particular passages from Aristotle and Pliny, giving little attention to other authors. This is unfortunate, because the two passages from Aristotle and Pliny that he regarded as describing a giant sea serpent are instead suggestive, in the first case, of a shark or a sea snake ("a black cylindrical beam" of unspecified length) and, in the second case, of a breaching whale ("rising up like a huge column and belching out a kind of deluge"), as Jules Cotte had already shown. In recent decades, Richard Ellis generally deferred to the work of Heuvelmans for the ancient period, while John Boardman as well as John K. Papadopoulos and Deborah Ruscillo discussed sea monsters more from the mythological and artistic than from the scientific point of view.[3]

As for large land snakes, Hans Gossen and August Steier in 1921 compiled many ancient references but did not systematically analyze their collected data. Rather, they simply grouped the snakes alphabetically under their ancient rubrics and gave modern taxonomic identifications whenever possible.[4] With few exceptions, modern scholars have dismissed most of the reported large serpents (terrestrial or aquatic) as ordinary snakes—without, however, presenting data and analysis adequate to show how they reached such a conclusion and certainly without tracing the chronological record of these reports throughout antiquity.

The full treatment given here focuses attention first on a famous incident at the Bagradas or Bagrada (modern Medjerda) River in North Africa in 256 B.C. This event had important repercussions down through antiquity into the Middle Ages, as will be shown. Next, further serpent reports out of Africa, India, the Middle East, and Europe are collected. These allow the impact of Alexander the Great's expedition into India to be assessed by contrasting the growth of the Alexander Romance—a collection of legends about Alexander's expedition—with the actual facts about snakes. Finally, the reception of these ancient historical

[3] Erich Pontoppidan, *The Natural History of Norway* (London: Linde, 1755), Vol. 2, pp. 195–210; A. C. Oudemans, *The Great Sea-Serpent: An Historical and Critical Treatise* (Leiden: Brill, 1892); Bernard Heuvelmans, *In the Wake of the Sea-Serpents* (New York: Hill & Wang, 1968); Aristotle, *History of Animals* 532b18–22; Pliny the Elder, *Natural History* 9.8; Jules Cotte, *Poissons et animaux au temps de Pline: Commentaires sur le livre IX de l'Histoire naturelle de Pline* (Paris: Lechevalier, 1944); Richard Ellis, *Monsters of the Sea* (New York: Knopf, 1994); John Boardman, "'Very Like a Whale': Classical Sea Monsters," in *Monsters and Demons in the Ancient and Medieval Worlds,* ed. A. E. Farkas, P. O. Harper, and E. B. Harrison (Mainz: Zabern, 1987); and John K. Papadopoulos and Deborah Ruscillo, "A *Ketos* in Early Athens: An Archaeology of Whales and Sea Monsters in the Greek World," *American Journal of Archaeology,* 2002, *106:*187–227.

[4] Hans Gossen and August Steier, "Schlange," in *Real-Encyclopädie der classischen Altertumswissenschaft,* ed. A. F. von Pauly and G. Wissowa, Vol. 2A, Pt. 1 (Stuttgart: Metzler, 1921), cols. 494–557. See also the updates by A. S. F. Gow and A. F. Scholfield, *Nicander: The Poems and Poetical Fragments* (Cambridge: Cambridge Univ. Press, 1953), pp. 18–21; John Scarborough, "Nicander's Toxicology, I: Snakes," *Pharmacy in History,* 1977, *19:*3–23; and Liliane Bodson, "Observations sur le vocabulaire de la zoologie antique: Les noms de serpents en grec et en latin," *Documents pour l'Histoire du Vocabulaire Scientifique,* 1986, *8:*65–117.

reports by the earliest medieval scholars provides a basis of support for the many modern studies that have traced the development of serpentology from the early Middle Ages on.

### THE BAGRADAS RIVER INCIDENT

In the late summer of 256 B.C., midway through the First Punic War, a Roman consular army invaded North Africa. Landing at Cape Bon in what is now Tunisia, the army proceeded southwest down the long peninsula into the thickly inhabited districts around Carthage, capturing the hilly open country and some four hundred towns and fortresses. Polybius (ca. 150 B.C.), our main authority, does not state how long this operation lasted, but the large number of Roman acquisitions (even allowing for rapid capitulation in many cases) suggests a campaign of months rather than days. Although Polybius named only the towns of Aspis (modern Kelibia?), Adys (modern Oudna?), and Tunis, we may take the mutual distances of these towns (some tens of miles) as indicative of the range of Roman operations around Carthage.[5] The rich agricultural districts to the northwest—especially the strategic town of Utica, a little west of the mouth of the Bagradas River—fall easily within this range and in any case posed an obvious target for the Roman army. It is, therefore, not at all improbable, though J. F. Lazenby and David Wardle raised some questions about it, that the Romans had both enough time and enough motive to reach the Bagradas River, the major drainage conduit in the region, which spills into the Mediterranean Sea about 15 miles from Carthage.[6]

Polybius never mentioned that the Roman expeditionary force, which was now under the sole command of the consul Marcus Atilius Regulus, was encamped by the Bagradas River. On the other hand, this detail is related by many other authorities in connection with the incident I intend to discuss. It must be remembered that the First Punic War appears in Polybius's history only as a part of his introduction and was not accorded a full-scale treatment. Furthermore, by his own acknowledgment he was writing mainly political and military history, and he roundly blamed other historians for reporting sensational incidents merely in order to entertain readers.[7]

Fortunately, other ancient historians were not so fastidious or so narrow in their professional outlook. None of the many writers whose extant works mention the Bagradas River incident, however, lived earlier than the first century A.D. Moreover, they cited as their authorities only Tubero and Livy, who were historians of the first century B.C. The most detailed account is preserved by Orosius (ca. A.D. 417), who probably derived it from the now lost Book 18 of Livy's *Roman History:*

> Regulus, chosen by lot for the Carthaginian War, marched with his army to a point not far from the Bagradas River and there pitched his camp. In that place a reptile of astonishing size devoured many of the soldiers as they went down to the river to get water. Regulus set out with his army to attack the reptile. Neither the javelins they hurled nor the darts they rained upon its back had any effect. These glided off its horrible network of scales as if from a slanting

[5] Polybius, *Histories* 1.29–30. See also Florus, *Epitome* 1.18.19; Appian, *Punic Wars* 1.3; Eutropius, *Breviary* 2.21; and Orosius, *Against the Pagans* 4.8. For modern place names see M. F. Fantar, "Régulus en Afrique," in *Punic Wars,* ed. H. Devijver and E. Lipiński (Leuven: Peeters, 1989), pp. 75–84.

[6] Ettore Pais, *Storia di Roma durante le Guerre Puniche* (Rome: Optima, 1927), p. 307; J. F. Lazenby, *The First Punic War: A Military History* (Stanford, Calif.: Stanford Univ. Press, 1996), p. 100; and David Wardle, *Valerius Maximus: Memorable Deeds and Sayings,* Bk. 1 (Oxford: Clarendon, 1998), p. 288.

[7] Claudine Herrmann, "Le cas d'Atilius Regulus," *Iura,* 1963, *14:*159–175. Polybius's philosophy of history is discussed in J. B. Bury, *The Ancient Greek Historians* (New York: Macmillan, 1909).

> testudo of shields and were in some miraculous fashion turned away from its body so that the creature suffered no injury. Finally, when Regulus saw that it was sidelining a great number of his soldiers with its bites, was trampling them down by its charge, and driving them mad by its poisonous breath, he ordered *ballistae* brought up. A stone taken from a wall was hurled by a *ballista;* this struck the spine of the serpent and weakened the constitution of its entire body. The formation of the reptile was such that, though it seemed to lack feet, yet it had ribs and scales graded evenly, extending from the top of its throat to the lowest part of its belly and so arranged that the creature rested upon its scales as if on claws and upon its ribs as if on legs. But it did not move like the worm, which has a flexible spine and moves by first stretching its contracted parts in the direction of its tiny body and then drawing together the stretched parts. This reptile made its way by a sinuous movement, extending its sides first right and then left, so that it might keep the line of ribs rigid along the exterior arch of the spine; nature fastened the claws of its scales to its ribs, which extend straight to their highest point; making these moves alternately and quickly, it not only glided over levels, but also mounted inclines, taking as many footsteps, so to speak, as it had ribs. This is why the stone rendered the creature powerless. If struck by a blow in any part of the body from its belly to its head, it is crippled and unable to move, because wherever the blow falls, it weakens the spine, which stimulates *the feet of the ribs* and the motion of the body. Hence this serpent, which had for a long time withstood so many javelins unharmed, moved about disabled from the blow of a single stone and, quickly overcome by spears, was easily destroyed. Its skin was brought to Rome—it is said to have been one hundred and twenty feet in length—and for some time was an object of wonder to all.

(See cover illustration.) All of our ancient authorities agree on the great length of the reptile. Eight of them provide exactly the same value for the length, one gives a rounded number, and three more merely refer to the reptile's huge size.[8] Cassius Dio (ca. A.D. 229), who is quoted by Zonaras and John of Damascus, mentioned that the thickness of the reptile's body was proportionate to its length and added that the flayed skin was measured at the instruction of the senate at Rome. The jawbones, according to Pliny the Elder (A.D. 77), were also shipped to Rome: along with the skin, they survived in a temple there down to the Numantine War, which ended in 133 B.C.[9]

Contrary to the testimony of Orosius, seven ancient authors claim that the reptile was felled by numerous blows from more than one *ballista.* For this assertion, Aulus Gellius cited Tubero and Valerius Maximus cited Livy. In any case, according to Valerius Maximus, after its demise the reptile's blood and innards polluted the local air and water for a considerable time. Much later, the strange episode was held to portend the defeat and capture of the general Regulus early the following year.[10]

[8] Orosius, *Against the Pagans* 4.8, trans. by Irving W. Raymond, *Seven Books of History Against the Pagans: The Apology of Paulus Orosius* (New York: Columbia Univ. Press, 1936), pp. 170–171. I have made a few changes in Raymond's translation; the phrase "the feet of the ribs" is italicized in light of the discussion below. See also the summary (*Periocha*) of Livy's Book 18. The eight sources that note the reptile's length as 120 feet are Valerius Maximus, *Memorable Deeds and Sayings* 1.8, ext. 19; Pliny the Elder, *Natural History* 8.37; Aulus Gellius, *Attic Nights* 7.3; Vibius Sequester, *Geography,* s.v. "Bagrada"; Orosius, *Against the Pagans* 4.8; Nepotianus, *Epitome* 1.8, ext. 19; John of Damascus, *Dragons* 1; and Zonaras, *Annals* 8.13. The rounded number of 100 cubits (about 150 feet) is offered by Silius Italicus, *Punica* 6.153 (whose full version of the story is told in 6.140–293, 6.677–679). Those who simply describe the monster as huge are Seneca, *Letters* 82.24; Florus, *Epitome* 1.18.20; and Arnobius, *Against the Pagans* 7.46(43).

[9] The temple remains unidentified. Fowler suggested that the relic was presented as a religious offering to the temple of Aesculapius on Tiber Island: W. Warde Fowler, *Roman Essays and Interpretations* (Oxford: Clarendon, 1920), pp. 178–181. Another possible site is the Capitoline temple of Jupiter, Juno, and Minerva, which was the repository of many military trophies and became the scene of a destructive riot in 133 B.C.: Velleius Paterculus, *Roman History* 2.3.2; Plutarch, *Tiberius Gracchus* 19–21; and Appian, *Civil Wars* 1.15–16. It is worth recalling that serpents were sacred to Juno (Hera) as well as to Aesculapius. The Garden of the Hesperides, which was guarded by Hera's great serpent, lay in North Africa.

[10] Valerius Maximus, Seneca, Pliny the Elder, Silius Italicus, Aulus Gellius, Nepotianus, and Zonaras point to

What are we to make of this story? The Bagradas River creature is always referred to by our ancient authorities as a *serpens*—traditionally meaning a large snake. Valerius Maximus specifically noted what seemed to be tail coils in order to identify the creature as a snake. Similarly, Pliny the Elder gave as a comparative the *boa* snakes, and Arnobius offered other snake examples. Silius Italicus, because he was writing epic poetry, enhanced the snake image by adding a crest and a three-forked tongue, stock Virgilian features.[11]

Modern commentators have varied widely in their interpretations. If the creature was a known reptile of some modern kind, then B. C. Niebuhr, Robert Gessler, W. Warde Fowler, Ettore Pais, and Karl Shuker agree that its reported size must have been greatly exaggerated. Niebuhr went so far as to suggest that it was all an invention of Naevius for his epic poem (now lost) about the First Punic War, in which he had served.[12] However, the many technical details given by Orosius are not likely to have been invented or even to have appeared in an epic poem. For the same reason, we may reject the outright dismissal of the story by J. F. Lazenby and Yann Le Bohec. It is interesting to observe, however, that most other commentators—Edward L. Bassett, Claudine Herrmann, Michel Martin, François Spaltenstein, Uwe Fröhlich, and David E. Jones—have remained noncommittal.[13] Toward the other extreme are those scholars who have regarded the story as being true but containing exaggerations. Gessler's identification of the creature as a Nile crocodile has been adequately refuted by Fowler, who, like Shuker, instead proposed a huge water serpent of some now-extinct species. The most extreme view is that of Pontoppidan, who suggested that the creature was a monstrous sea serpent of unknown type.

If we accept the details of the story as true, a close examination reveals only one fact that stands in opposition to the original idea that this was a large snake, such as a python. The troublesome fact is the creature's universally reported length of 120 feet.[14] No python (or other snake) known today has a length exceeding about 30 feet.[15] Otherwise, the reported features are credibly those of a snake: the sinuous, lateral movement; the even grade

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numerous blows from more than one *ballista.* For interpretations of this episode as portending the defeat of Regulus see Livy, *Periocha,* Book 18; Silius Italicus, *Punica* 6.286–290; and Florus, *Epitome* 1.18.20. See also François Spaltenstein, *Commentaire des Punica de Silius Italicus (livres 1 à 8)* (Geneva: Droz, 1986), p. 410.

[11] Virgil, *Aeneid* 2.206–207, 2.475.

[12] B. C. Niebuhr, *Lectures on the History of Rome, from the Earliest Times to the Fall of the Western Empire* (London: Taylor, Walton & Maberly, 1849), pp. 30–31; Robert Gessler, "Zur früheren Verbreitung des Nilkrokodils," *Zoologischer Beobachter (Zoologische Garten),* 1915, *56:*257–263; Gessler, "Atilius Regulus in Africa serpentem portentosae magnitudinis cum magna militum clade occidit (Liv. Epit. 18)," *Korrespondenzblatt Württembergs,* 1916, *23:*38–43; Fowler, *Roman Essays and Interpretations* (cit. n. 9); Pais, *Storia di Roma* (cit. n. 6); and Shuker, *Dragons* (cit. n. 1), pp. 26–29.

[13] Lazenby, *First Punic War* (cit. n. 6); Yann Le Bohec, *Histoire militaire des guerres puniques* (Monaco: Rocher, 1996), p. 88; Edward L. Bassett, "Regulus and the Serpent in the *Punica,*" *Classical Philology,* 1955, *50:*1–20; Herrmann, "Le cas d'Atilius Regulus" (cit. n. 7), p. 159; Michel Martin, "Le monstre de Bagrada," *Eidolon,* 1979, *7:*21–42; Spaltenstein, *Commentaire des Punica* (cit. n. 10), p. 400; Uwe Fröhlich, *Regulus, Archetyp römischer Fides* (Tübingen: Stauffenburg, 2000), pp. 186–189; and Jones, *Instinct for Dragons* (cit. n. 1), pp. 138–139.

[14] Units of length cited by the ancient authorities include the foot, cubit, fathom, and plethrum. It is sufficient here to equate the Roman foot with the modern English foot and to convert the variable Greek and Roman cubit everywhere using the approximation 1 cubit = 1½ feet. Also adopted are 1 fathom = 6 feet and 1 plethrum = 100 feet. To convert to the metric system, note that 1 foot = 0.305 meter. But for reasons that will become clear, all lengths will be quoted in the original units of the ancient texts, except that the cubit is here converted to feet (flagged as *feet).

[15] I consulted numerous references on modern snakes for the present study, but only five will be cited here: H. W. Parker and K. P. Schmidt, "Snakes," in *Encyclopaedia Britannica* (Chicago: Benton, 1962); Parker and Schmidt, "Python," *ibid.;* Clifford H. Pope, *The Giant Snakes* (New York: Knopf, 1973); Chris Mattison, *The Encyclopedia of Snakes* (New York: Facts on File, 1995); and John C. Murphy and Robert W. Henderson, *Tales of Giant Snakes: A Historical Natural History of Anacondas and Pythons* (Malabar, Fla.: Krieger, 1997).

of scales along the body; the rib and spine structure underneath the scaly skin (evidently detected in a postmortem examination); and the large number of ventral scutes enabling progress over uneven surfaces. It is noteworthy, too, that Orosius did not describe any obvious differentiation of neck, body, and tail—again, support for the idea of a large snake.

What, then, about the reported length? Three alternative explanations may be suggested. First, this may not have been a true snake—as Pontoppidan conjectured without giving specific reasons. Second, Orosius's original source may have recorded the number of ribs, or rib pairs, as 120, a figure that later became misinterpreted as the number of "feet" of the animal's length owing to confusion arising from the source's mention of "the feet of the ribs." This explanation seems plausible given that the number of ribs in a snake may exceed 300 pairs. A third possibility is that some snakes two millennia ago may have attained lengths of 120 feet. To credit this, one would have to locate other reliable ancient testimony to the same effect. The discussion therefore now turns to the largest snakes recorded in classical antiquity.

## TERRESTRIAL SERPENTS

The adjective "terrestrial" is here meant to refer to those serpents that live primarily on land. Although there exist some snakes, like pythons, that also spend time in the water and even go to sea, these creatures will be grouped with the landlubbers. Terms in Latin authors that are used to refer to the largest terrestrial snakes include, besides *serpens,* the very general *anguis,* as well as *draco, vipera,* and *boa;* the Greek equivalents are ὄφις, δράκων, and ἔχιδνα (or ἔχις). Our English words for large snakes—"serpent," "dragon," "viper," and "boa"—derive from these ancient terms, as does our word "python" (from Πύθων, the great snake killed by Apollo at Delphi). (See Figure 2.) Generally speaking, the ancient authors distinguished between the highly venomous biting snakes (vipers) and the nonvenomous squeezing and biting snakes (pythons and boas). Otherwise, their taxonomy was very crude, reflecting mostly superficial characteristics such as visual appearance, living habits, and noxious effects.

### *Africa*

Aristotle (ca. 350 B.C.) presented a brief report that huge snakes once entered the sea off North Africa and overturned a fleeing trireme (a ship about 120 feet long).[16] This feat indirectly supports the Roman account of a huge snake at the Bagradas River in 256 B.C.

Diodorus Siculus (ca. 30 B.C.), in describing the snakes of ancient Ethiopia—which meant all lands south of Egypt—publicized the fabulous reports that the biggest snakes there attacked elephants and measured up to 150 *feet (cubit-converted feet) long. Distrusting so large a figure, however, he also told with more confidence of a well-authenticated case in the time of Ptolemy II Philadelphus, King of Egypt (283–246 B.C.), when the king exhibited a tamed Ethiopian snake 45 *feet long at Alexandria. This snake had been netted after a terrifying hunt in which the animal first killed two hunters by biting one and squeezing the other and then resisted an onslaught of arrows and stones. Pausanias (ca. A.D. 150) and Philumenus (ca. A.D. 180) also mentioned African snakes 45 *feet long, perhaps from the same source, Agatharchides (ca. 120 B.C.), that Diodorus used. On the other hand, Aelian (ca. A.D. 225) said that Ptolemy Philadelphus had actually received two

[16] Aristotle, *History of Animals* 606b9–14.

***Figure 2.*** *Python in the grotto at Delphi. Greek vase (fifth century B.C.). By permission of the Bibliothèque Nationale de France, Paris. (BNF Vase 306.)*

snakes, 21 *feet and 19½ *feet long; it may be more than coincidental that the two lengths add up to nearly 45 *feet. He also cited Nymphis (ca. 250 B.C.) for the occurrence of 22½-*foot “vipers” near the Red Sea. Otherwise, he repeated the traditional lore for the biggest snakes given by Diodorus. In southern Egypt, some desert monks (ca. A.D. 400) also reported a snake 22½ *feet long, according to their fellow monks Rufinus and Palladius, but it was not classified as to type.[17]

Clearly, there exists no certain ancient evidence for any African snake larger than the modern rock python (*Python sebae*), which can grow to 30 feet. The possible exceptions are Ptolemy Philadelphus’s large specimen and the reptiles reported in the two North African incidents. In modern times, rock pythons have not ranged north of the southern Sahara Desert. Pliny the Elder stated, however, that large snakes would sometimes swim in small groups across the Red Sea from Ethiopia to Arabia.[18] If his report is true, this might have extended their eastward range in antiquity.

### *India*

The large snakes of India are described by more extant ancient writings (mostly as brief mentions in literary fragments) than those of any other country, thanks to Alexander the Great’s career of conquest there in 327–325 B.C. Participants in that remarkable adventure have provided the following dimensions for the largest snakes. Nearchus, commander of Alexander’s fleet, and Aristobulus, a key army technician, who were the most sober and reliable of the Alexander historians, said that they saw snakes about 24 *feet and 13½ *feet long, respectively, although they also heard rumors of larger ones. Such rumors were eagerly repeated by Onesicritus, Nearchus’s lieutenant, who told of some Indian ambassadors whose king, Abisarus, reportedly kept as pets two snakes 120 and 210 *feet in length. Alexander’s army is also said to have passed a cavern containing a sacred snake, reputed by the Indians to measure 105 *feet, but all the army actually saw was its head, with eyes that seemed to the terrified soldiers to be as large as round shields.[19] The Indians were obviously playing jokes on the unwelcome Macedonians, whose eager king was always pressing to behold such ophiological wonders.

During the two generations immediately following Alexander’s death in 323 B.C., legends of huge ox-swallowing and elephant-toppling snakes in India whetted the public’s appetite for marvels, feeding the nascent Alexander Romance. Megasthenes and Deimachus, two Greek ambassadors in India, were particularly to blame. One of the post-Alexandrian writers consulted by Maximus of Tyre (ca. A.D. 180) said that the great snakes were as long as 5 plethra (500 feet). The Greek historian Cleitarchus, however, more soberly transmitted Nearchus’s reported length of 24 *feet.[20]

[17] Diodorus Siculus, *Library of History* 3.10, 3.36–37; Pausanias, *Description of Greece* 2.28.1; Philumenus, *Poisonous Animals* 30; Agatharchides in Photius, *Bibliotheca* 250; Aelian, *Nature of Animals* 2.21, 16.39, 17.3; Rufinus, *History of Monks* 8; and Palladius, *Lausiac History* 52. From an unknown source Pliny the Elder, *Natural History* 8.35, gives 30 *feet as the length of large African snakes. The reported length of the snake exhibited by Ptolemy Philadelphus has been defended in Liliane Bodson, “A Python (*Python sebae* Gmelin) for the King,” *Museum Helveticum,* 2003, *60:*22–38.

[18] Pliny the Elder, *Natural History* 8.35.

[19] For the various reports see Strabo, *Geography* 2.1.9, 15.1.28, 15.1.45; Arrian, *Indica* 15.10; and Aelian, *Nature of Animals* 16.39. For the report of the sacred snake see *ibid.* 15.21.

[20] Regarding the reports of the Greek ambassadors see Strabo, *Geography* 2.1.9; Pliny the Elder, *Natural History* 8.36; Aelian, *Nature of Animals* 16.41; and Solinus, *Collection* 26. For the figure of 5 plethra see Maximus of Tyre, *Dissertations* 8.6. For more sober views see Cleitarchus in Aelian, *Nature of Animals* 17.2; and Diodorus Siculus, *Library of History* 17.90. Pliny the Elder, *Natural History* 8.35, also credits a number on the order of 30 *feet.

The Augustan age received new, independent information about large snakes in India. Strabo, in the course of traveling around Egypt, saw a snake brought from India that was about 13½ *feet in length.[21] Suetonius (ca. A.D. 120), who had personal access to Augustus's imperial archives, informs us that this emperor displayed "a snake of 75 *feet in front of the Comitium [Roman assembly area]." Since this information is included along with reports of public exhibitions of a rhinoceros and a tiger, we may assume that the snake came from India. But what about the "75 *feet"? Pausanias and Philostratus (ca. A.D. 210) claimed that Indian snakes could grow to 45 *feet or even more, while Philostorgius (ca. A.D. 425) said that he saw in Roman territory the skins of Indian snakes measuring up to 15 fathoms (90 feet) in length. Since the modern Indian python (*P. molurus*) reaches only 20 feet, the lengths mentioned by Suetonius and Philostorgius—who otherwise should be regarded as reliable authorities—suggest either the existence of much larger specimens in the historical past or, more likely, a display of circus-show hyperbole by the Roman exhibitors.[22] Antiquity doubtless had its P. T. Barnums, too.

Ancient reports of enormously long worms and eels in the major rivers of India also survive, but the descriptions often sound more like pythons. Ctesias (ca. 400 B.C.) mentioned bulky worms more than 10½ *feet long in the Indus River and reported that they crawl out onto land at night and devour large animals such as oxen. Statius Sebosus (ca. A.D. 50) claimed that some blue worms in the Ganges River are endowed with pairs of gills measuring 9 *feet in length and are strong enough to carry off elephants with their teeth. Although some present-day aquatic worms can grow to over 12 feet in length and can consume small animals, it is not possible to sort out whether the ancient accounts are mixing up worms and snakes. Similarly, Pliny the Elder and Solinus (ca. A.D. 200) said that eels (*anguillae*) in the Ganges River reach 30 feet in length, but they were probably referring to snakes (*angues*).[23]

### *Middle East*

Aelian transmits brief accounts of giant snakes on the island of Chios, as well as near Ephesus and in Phrygia—the last reportedly spawning snakes up to 60 feet in length. But

[21] Strabo, *Geography* 15.1.45. More generally, archaeological finds in India as well as other historical testimony indicate a renewal of direct Western contact with India during the Augustan age; see R. E. M. Wheeler, *Rome Beyond the Imperial Frontiers* (London: Bell, 1954). Aggressive Roman traders in the first to sixth centuries A.D. might even have brought *Python reticulatus,* the largest of the pythons, from Southeast Asia to the West; the longest modern specimens reach slightly over 30 feet.

[22] Suetonius, *Augustus* 43; Pausanias, *Description of Greece* 2.28.1; Philostratus, *Apollonius of Tyana* 3.6; and Philostorgius, *Ecclesiastical History* 11, epitomized by Photius. Stretching a snake skin can increase its length by only a few percent; stitching together several snake skins can work wonders. Such frauds employing snakes seem to have been common in antiquity. I have already mentioned the Indian tricks played on Alexander the Great. The pseudo-priest of Aesculapius, Alexander of Abonoteichus (ca. A.D. 160), used both real snakes and hand-crafted models in his deceptions: Lucian, *Alexander the False Prophet* 12–16. Ancient frauds using various animals are well discussed in Mayor, *First Fossil Hunters* (cit. n. 2), Ch. 6.

[23] On the Indus River worms see Aelian, *Nature of Animals* 5.3; and Ctesias in Photius, *Bibliotheca* 72. Those in the Ganges River are mentioned by Statius Sebosus, cited in Pliny the Elder, *Natural History* 9.46; and Solinus, *Collection* 53. Pliny mistakenly quotes the length of Ganges worms as 90 (not 9) *feet; Solinus usually follows Pliny but sometimes provides a needed correction. On present-day aquatic worms see W. R. Coe, "Nemertina," in *Encyclopaedia Britannica* (Chicago: Benton, 1962). Regarding the Ganges "eels" see Pliny the Elder, *Natural History* 9.4; and Solinus, *Collection* 53. Kitchell traces the development of Ganges worm and eel lore through the Middle Ages, although he misstates some of the numbers and representations in Aelian, Pliny, and Solinus: Kenneth F. Kitchell, Jr., "The View from Deucalion's Ark: New Windows on Antiquity," *Classical Journal,* 1993, *88:*341–357.

the Phrygian reports are only hearsay, according to Aelian, and so we are entitled to ignore them.[24]

Arabian snakes are sometimes reported as being very large. Aelian cited a certain Alexander (probably Alexander of Myndus, ca. A.D. 25) for the existence of snakes 60 *feet long in the area of the Arabian Sea. Aelian's contemporary Solinus, however, referred to these snakes only as more than 30 *feet long and as having their lair in the Strait of Hormuz, which leads to the Arabian Sea. Philostratus, another contemporary, claimed that they descend from their mountain homes and swim far out to sea.[25] These were most likely Indian pythons, roaming somewhat westward of their present range. This inference is consistent with Solinus's remark that some Indian snakes swim way out into the Indian Ocean, well beyond their normal range. Accordingly, some of them may have strayed permanently west of the Indus River valley.

### *Europe*

The only ancient account of a truly large, apparently indigenous Italian snake occurs in the Roman prodigy list of Cassius Dio (ca. A.D. 229) for the year 32 B.C., where it is said that a two-headed serpent 85 feet in length appeared in Etruria and was killed by lightning after doing much harm. The provenance of such a fantastic report at so well documented a period and place is hard to discern. The account looks like a borrowing from standard dragon lore. It recalls Hesiod's myth of Typhon, a monster with a hundred snake heads who was killed by Zeus's lightning bolts.[26] The purpose of such a fiction in 32 B.C. seems to have been largely political: at that time, two powerful leaders, Octavian and Mark Anthony, were vying militarily for dominion over the Roman world. Dio implies this message very clearly by linkage.

Pliny the Elder and Solinus wrote of native Italian *boae,* a term generally understood today to refer to vipers, whose length normally does not exceed 3 feet.[27] Giving an example of a *boa,* however, they said that one swallowed a small child on the Vatican Hill at Rome during the reign of the emperor Claudius (A.D. 41–54). (See Figure 3.) This *boa* was probably a python, imported from Africa or India.

## MARINE SERPENTS

Contrary to popular impression, ancient reports of sea creatures that people of the time regarded as sea monsters but are different from things that we can easily identify today are surprisingly infrequent outside the mythological literature. Oudemans, Heuvelmans, and Ellis, however, have clearly recognized this fact. The Latin and Greek terms used to describe these rare, mysterious monsters are *anguis,* δράκων, κῆτος, and σκολόπενδρα. On the other hand, it must be emphasized that the ancient authors were unable to differentiate between fact and fiction in the case of most of these sea creatures. Making this

[24] Aelian, *Nature of Animals* 2.21, 16.38–39.

[25] *Ibid.* 17.1; Solinus, *Collection* 53, 55; and Philostratus, *Apollonius of Tyana* 3.8.

[26] Cassius Dio, *Roman History* 50.8.4; and Hesiod, *Theogony* 820–868 (other snake-headed monsters are discussed at 295–336). The two-headedness of the Etruscan snake recalls the description of the *amphisbaena,* an unidentified African snake that appeared to possess a head at each end of its body: Pliny the Elder, *Natural History* 8.85; Nicander, *Theriaca* 372–383 (with scholium); Solinus, *Collection* 28; Aelian, *Nature of Animals* 9.23; and Philumenus, *Poisonous Animals* 27. The *amphisbaena* is probably a real animal, according to Gow and Scholfield, *Nicander: Poems and Poetical Fragments* (cit. n. 4), pp. 177–178.

[27] Pliny the Elder, *Natural History* 8.37; and Solinus, *Collection* 2. Gossen and Steier, "Schlange" (cit. n. 4), col. 530, identify *boae* as vipers.

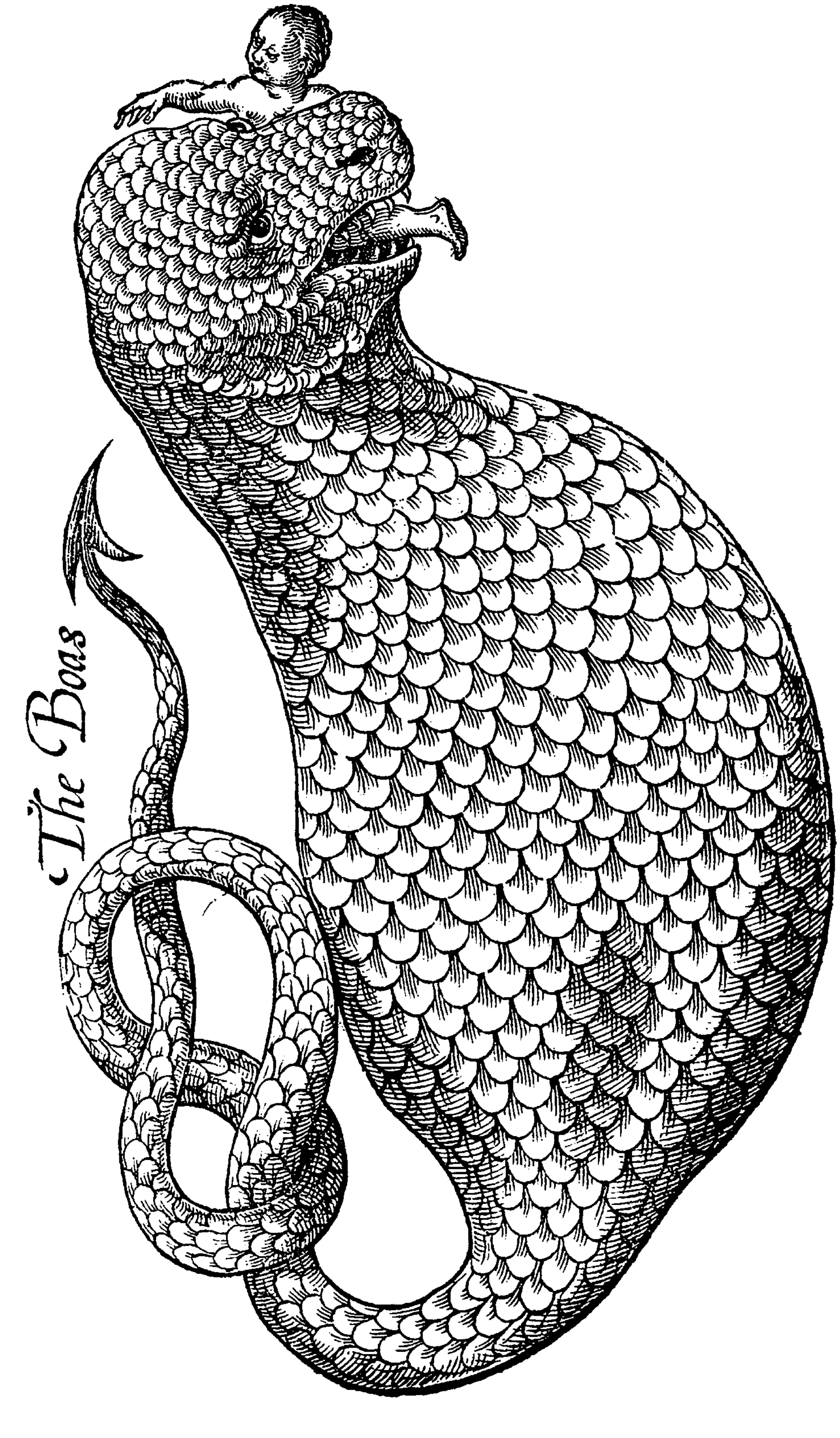


***Figure 3.*** *Boa devouring a child. Engraving from Edward Topsell,* The History of Four-Footed Beasts and Serpents *(London, 1658). By permission of the Rare Books Division, New York Public Library, Astor, Lenox, and Tilden Foundations.*

distinction has required a modern judgment call, but such a call is still subject to much dispute and uncertainty.

The most general term used is κῆτος (Latin *cetus*). In nonmythological literature a creature so designated can almost always be identified with a whale, dolphin, or large fish, although in mythology and art it routinely appears as some kind of monster, often a hybrid of different kinds of animals, not all of them marine.[28] It need not concern us here.

A sea monster known as the leviathan is mentioned in the Bible (Old Testament) and in north Phoenician mythological texts from Ugarit (fourteenth century B.C.).[29] The leviathan has been identified variously as a crocodile, a whale, a hippopotamus, and a sea serpent. Like the semi-aquatic behemoth and other fabulous sea monsters of the protohistorical period, the leviathan does not really enter later history except as myth or legend. It will therefore not be profitable to discuss it further.

In 210 B.C., according to a Roman prodigy list recorded in Livy, "snakes of a remarkable size leaped up and down in the manner of fish sporting about at Tarracina in the sea not far from the harbor." The town of Tarracina lies about 65 miles south of Rome. If, as seems likely, the "snakes" were viewed from the harbor itself, distance might have played games with the eyes, and therefore we might interpret the "snakes" as simply a line of leaping dolphins or the flailing arms of a giant squid (or octopus). Or perhaps they were the bodily undulations of Heuvelmans's "super-eel," a speculative creature dubiously inferred from a few modern sightings.[30] (See Frontispiece.)

A well-documented case of a sea monster about 100 feet long and over 7 feet wide both in jaw size and in body size, displaying "scales" 4 feet long, was reported by the Syrian polymath Posidonius (ca. 75 B.C.). His account was quoted by Strabo in a discussion about the Syrian coastal plain:

> As for the plains, the first, beginning at the sea, is called Macras, or Macra-Plain. Here, as reported by Posidonius, was seen the fallen dragon, the corpse of which was about a plethrum in length, and so bulky that horsemen standing by it on either side could not see one another; and its jaws were large enough to admit a man on horseback, and each flake of its scales exceeded an oblong shield in length.

Although the "scales" suggest some kind of sea dragon, as they did to Posidonius, the large size of the jaw does not, except for certain extinct marine reptiles like pliosaurs and mosasaurs. However, the term "scaly" was sometimes used by the ancients to describe the skin of a whale; it is therefore likely that this monster was in fact a large whale.[31] On the

[28] In addition to the works of Oudemans, Heuvelmans, Cotte, Ellis, Boardman, and Papadopoulos and Ruscillo cited in note 3, above, many other references for sea creatures could be given: e.g., Richard Ellis, *Encyclopedia of the Sea* (New York: Knopf, 2000).

[29] In the Bible see esp. Psalms 74:13–14, 104:25–26; Isaiah 27:1; Job 41:1–34. See also Edmond Jacob, *Ras Shamra-Ugarit et l'Ancien Testament* (Neuchatel: Delachaux & Niestlé, 1960), pp. 74, 94–95; and John Day, *God's Conflict with the Dragon and the Sea* (Cambridge: Cambridge Univ. Press, 1985). The behemoth in Job 40:15–24 has been labeled a crocodile, a hippopotamus, an ox, and a dragon.

[30] Livy, *Roman History* 27.4.13; and Heuvelmans, *In the Wake of the Sea-Serpents* (cit. n. 3), pp. 543–544.

[31] Strabo, *Geography* 16.2.17, trans. by Horace L. Jones, *Strabo: Geography,* Vol. 7 (Cambridge, Mass.: Harvard Univ. Press, 1930), pp. 261–263. For a description of the skin of a whale as "scaly" see Arrian, *Indica* 39.4–5. In 58 B.C. bones alleged to be those of the sea monster that Perseus slew in order to save Andromeda were brought from Joppa (Jaffa) in Judaea to Rome; see Pliny the Elder, *Natural History* 9.11. The skeleton, 40 feet in length, was probably that of a whale or a shark. Mayor, *First Fossil Hunters* (cit. n. 2), pp. 138–139, thinks that it might have been a fake composite of whale and fossil bones, although she considers the Macras dragon a whale carcass. Papadopoulos and Ruscillo, "*Ketos* in Early Athens" (cit. n. 3), p. 213, appear to regard the Joppa bones as a whale skeleton.

other hand, since true fish (unlike mammals) continue to grow until they die, it is also possible that this was a species of large shark, even though no known modern shark exceeds about 50 feet in length (some prehistoric sharks approached 100 feet).

A still more puzzling creature was described by Aelian in his discussion of the unusual animals of his day:

> Now in the course of examining and investigating these subjects and what bears upon them, to the utmost limit, with all the zeal that I could command, I have ascertained that the Scolopendra is a sea-monster, and of sea-monsters it is the biggest, and if cast up on the shore no one would have the courage to look at it. And those who are expert in marine matters say that they have seen them floating and that they extend the whole of their head above the sea, exposing hairs of immense length protruding from their nostrils, and that the tail is flat and resembles that of a crayfish. And at times the rest of their body is to be seen floating on the surface, and its bulk is comparable to a full-sized trireme. And they swim with numerous feet in line on either side as though they were rowing themselves (though the expression is somewhat harsh) with thole-pins hung alongside. So those who have experience in these matters say that the surge responds with a gentle murmur, and their statement convinces me.

(See Figure 4.) The footlike appendages account for the name Scolopendra, since the common sea scolopendra was a type of myriapod worm, familiar to the ancient fishermen. Two epigrammatic poets also described the Scolopendra, although we cannot be certain that they were claiming actual occurrences of it. Theodoridas (ca. 225 B.C.) mentioned the large rib of a thousand-footed Scolopendra that washed up on the Calabrian shore in Italy, while Antipater (probably of Sidon, ca. 100 B.C.) described the mutilated remains of one that was 8 fathoms (48 feet) long, discovered on a Mediterranean beach.[32]

It is not immediately clear what the Scolopendra really was. No known creature, living or extinct, has possessed such a large number of flippers (or fins). If we are dealing with a large whale of about 120 feet in length, what appeared to be "feet" could have been suckerfish attached to its belly, as T. H. White has speculated.[33] Although White offers an alternative conjecture that the Scolopendra was a giant squid, this suggestion seems to be at greater variance with the reported mode of locomotion and with the creature's other physical characteristics. If it was in fact a whale, ripples in the water around its body could have resembled feet or could have been interpreted as having been caused by feet.

### RECEPTION OF SERPENT LORE IN THE EARLY MIDDLE AGES

The roots of medieval serpentology lie in the natural history, folklore, and mythology of classical antiquity. It is not my intention here to delve into the development of serpentology during the Middle Ages, a topic beyond the scope of this study. The present objective is to trace, in brief, the introduction of ancient serpent lore into the earliest medieval texts, with special emphasis on the content of natural history as opposed to that of primitive mythology.

During the Augustan age, the lexicographer Verrius Flaccus (as epitomized by Festus

[32] Aelian, *Nature of Animals* 13.23, trans. by A. F. Scholfield, *Aelian: On the Characteristics of Animals,* Vol. 3 (Cambridge, Mass.: Harvard Univ. Press, 1959), p. 123. On the common sea scolopendra see Aristotle, *History of Animals* 505b13–18, 621a6–12; Pliny the Elder, *Natural History* 9.145, 32.151; and Oppian, *Halieutica* 1.306–307, 2.424–433. For the poems of Theodoridas and Antipater see *Greek Anthology* 6.222, 6.223. Mayor, *First Fossil Hunters* (cit. n. 2), p. 264, regards the rib as a fossil.

[33] T. H. White, *The Bestiary: A Book of Beasts* (New York: Putnam, 1954), pp. 265–266. White incorrectly attributed the passage in Aelian to Pliny the Elder.

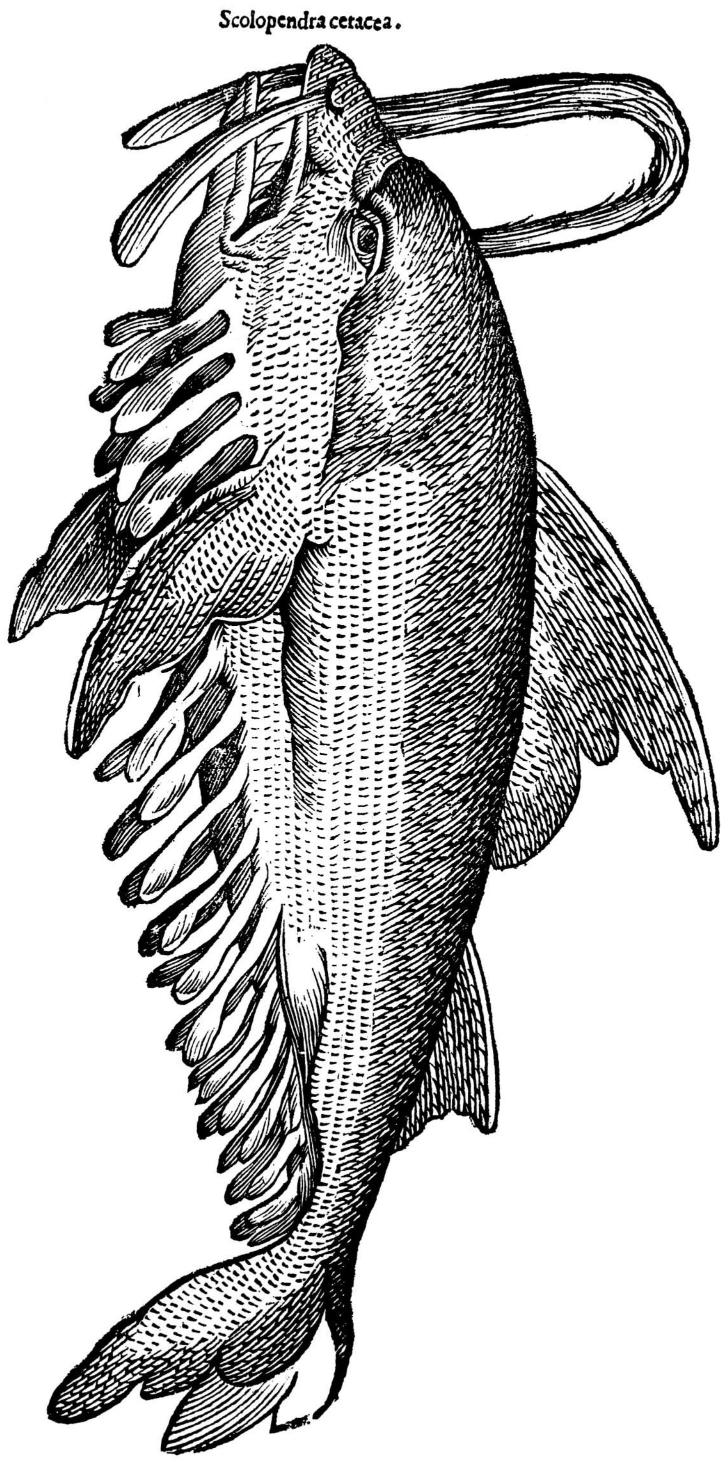


***Figure 4.*** Scolopendra cetacea. *Engraving from Ulisse Aldrovandi,* De animalibus insectis libri septem *(Bologna, 1638). By permission of the Science, Industry, and Business Library, New York Public Library, Astor, Lenox, and Tilden Foundations.*

in the second century A.D.) transmitted Greek tradition in categorizing the *dracones* etymologically by their keen eyesight. So too did Macrobius (ca. A.D. 400). The Greek δέρκεσθαι means "to see." The epic poet Lucan (A.D. 65) made particular mention of their golden sheen, and indeed the iridescent scales of some members of both *P. molurus* and *P. sebae* do glitter like gold or silver.[34] Philostratus also dwelt on this remarkable iridescence in his description of the mountain dragons of India, to which he added, probably drawing on the Alexander historians or their successors, a number of more fantastic details that closely resemble the features of our modern image of a dragon: fiery eyes, red crest, beard, and serrated back. Megasthenes, the Greek ambassador to India, and Lucan both included wings.[35] The ultimate source of these elements may be the tall tales—or even the myths—of the Indians, since African dragons usually were not so fantastically endowed by the ancients.

Most of the early medieval lore about sea serpents, on the other hand, springs from the Roman mythologizing poets, especially Virgil in the Augustan age. Virgil's fanciful description of the two sea serpents that attacked Laocoön and his sons—with their fiery eyes, red crests, and undulating backs—appears to be a forerunner of the similar description of the land dragon by Philostratus. Heuvelmans has conjectured that Virgil's sea serpents might have been rooted in reality, being the rarities known today as oarfish. The oarfish can grow to a length of over 20 feet, and though it is in fact a weak and harmless creature, its size and its blood-red mane, at the head of a dorsal fin that runs along a ribbon-like silvery body, make it an intimidating sight.[36]

A "scientific" differentiation was made in early medieval times between the huge dragon (*draco*) and the more ordinary snakes (*coluber, anguis,* and *serpens*). Although Virgil did not make this distinction and used the four terms interchangeably, it was introduced explicitly by the Christian writers Arnobius (ca. A.D. 300), Ambrose (ca. A.D. 390), and Isidore of Seville (A.D. 636) and by various authors of medieval bestiaries. Probably it appeared originally in one of the early versions of *Physiologus,* a Greek moralizing collection of natural history anecdotes composed between the second and fourth centuries A.D., which long served as a convenient source of zoological material for the bestiary writers.[37]

[34] Festus, *Epitome,* s.v. "Dracones"; Macrobius, *Saturnalia* 1.20; and Lucan, *Pharsalia* 9.727–733. This last is in contrast to Ovid, *Metamorphoses* 3.38, who described the serpents as blue, following Pseudo-Hesiod, *Shield of Heracles* 167.

[35] Philostratus, *Apollonius of Tyana* 3.6–8; Aelian, *Nature of Animals* 16.41; and Lucan, *Pharsalia* 9.730. Although Apollonius of Tyana (first century A.D.) is said to have visited India, it is unlikely that Philostratus took this description of dragons from Apollonius's biographers, since the textual matter is presented explicitly as background material. The crest was mentioned for non-Indian *dracones* by Juba II, King of Mauretania (ca. A.D. 20), in Pliny the Elder, *Natural History* 8.35 (who criticized Juba's error), and the beard by Nicander (second century A.D.), *Theriaca* 438–444 (with scholium), while Silius Italicus (ca. A.D. 100), *Punica* 6.219, described the mouth as smoking. Mayor, *First Fossil Hunters* (cit. n. 2), pp. 129–135, interprets the Indian dragons as inventions inspired by fossil bones from the Siwalik Hills, but the overall evidence from the time of the Alexander historians on strongly suggests living snakes, possibly with extraneous embellishments supplied by fossil discoveries.

[36] Virgil, *Aeneid* 2.201–227; and Heuvelmans, *In the Wake of the Sea-Serpents* (cit. n. 3), pp. 84–86. The Laocoön Group (first century B.C. or A.D.) in the Vatican Museum depicts the serpents as ordinary snakes of extraordinary length.

[37] Arnobius, *Against the Pagans* 7.46(43); Ambrose, *Hexameron* 5.2; Isidore of Seville, *Etymologies* 12.4.1–5; and White, *Bestiary* (cit. n. 33), pp. 165–167. Ambrose, however, describes only the viper in detail (5.7). The pagan scholar Servius (ca. A.D. 400), *Commentary on Virgil's Aeneid* 2.204, seems to be unaware of the Christian distinctions. On medieval bestiaries see, e.g., Willene B. Clark, "Zoology in the Medieval Latin Bestiary," in *Man and Nature in the Middle Ages,* ed. Susan J. Ridyard and Robert G. Benson (Sewanee, Tenn.: Univ. South Press, 1995), pp. 223–245.

In the early medieval bestiaries, some of the wilder flights of fancy of the Alexander historians and their successors seem to be missing. Although a few legends about the dragon—such as the red crest and the elephant-toppling ability—persist in these accounts, most of the other facts about serpents are correct. This must be due to the general medieval reliance on encyclopedic authorities like Pliny the Elder, Solinus, and Aelian. Another restraining factor, generally overlooked by modern scholars, is doubtless the Bagradas River incident, which crops up repeatedly in early medieval authors such as Arnobius, Orosius, and John of Damascus. Matter-of-fact accounts of medieval incidents involving serpents, like the story of St. Martin of Tours (ca. A.D. 375) and the river snake, must also have served as a reality check on the bestiary writers.[38] It is only much later that the extravagant picture provided by ancient sensationalists like Philostratus took over from the more cautious views of the early bestiarists.

**CONCLUSION**

To conclude: are we dealing with zoology or with cryptozoology? On the whole, the evidence is strong that most ancient reports of exceptionally large terrestrial serpents refer to snakes of the genus *Python.* The only reported aspects of these serpents that are problematic concern their maximum size and their geographical range. Before the modern-day decimation of many species of Eurasian animals, pythons may well have lived longer and ranged farther afield than today’s specimens. Estimates of the lengths of snakes that are not based on direct measurement, however, are subject to large possible error, as John Murphy and Robert Henderson have shown for modern pythons.[39] There is no solid evidence for any ancient African or Indian python longer than about 25 feet, which is comparable to the maximum size encountered today. So many ancient claims and rumors of snakes 45 feet in length or more survive, however, that it is hard to deny categorically that they actually existed.

As for the geographical range of pythons in antiquity, there is credible evidence that the Indian python extended somewhat westward of the Indus River valley, at least as far as the Strait of Hormuz. This interpretation is geographically more likely than that the sub-Saharan rock python ranged all the way across the Red Sea, Arabian Peninsula, and Persian Gulf. However, the dry southern Iranian habitat might have been unfavorable for the Indian python. In North Africa, pythons appear to have inhabited the Mediterranean coast to the west of Egypt. Several possible explanations for their presence there come to mind. These pythons might have been sub-Saharan or Indian pythons imported to, and then released from, Carthage or other cities in North Africa. Or they might have been sub-Saharan pythons that had made their way north across the Sahara during one of the more humid periods, when the vast desert stretching from the western Sahara to western China was pockmarked with lakes, marshes, and rivers. The most recent of these periods occurred about four thousand years ago. Although a core desert north of the Tropic of Cancer has

[38] Sulpicius Severus, *Dialogues* 3.9; Paulinus, *Life of St. Martin* 5.616–636; and Fortunatus, *Life of St. Martin* 4.272–283. At St. Martin’s command, a threatening snake swimming across a river turned back. In contrast, the dragon stories of St. Hilarion of Gaza (ca. A.D. 370) and of St. Donatus of Epirus (ca. A.D. 380) contain many exaggerations, drawn from the Greek myth of Apollo and the Python and from Indian lore: Jerome, *Life of St. Hilarion* 39; and Sozomen, *Ecclesiastical History* 7.26. St. George (ca. A.D. 303) and the dragon first appear together in the late Middle Ages, the legend being based in part on the Greek myths of the dragonslayers Perseus and Heracles.

[39] Murphy and Henderson, *Tales of Giant Snakes* (cit. n. 15), pp. 47, 55–56.

probably existed for millions of years, it might have been passable in places at various times. Or the pythons might have migrated down the Nile River valley. On the assumption that the reported North African pythons had been indigenous in the southern Mediterranean for at least several thousand years, they probably would have belonged to a different, unnamed species.[40] Habitat destruction and slaughter in the Mediterranean basin over many centuries during and after classical antiquity could easily account for their absence there today.

A handful of ancient reports do remain puzzling, however. Ostensibly, these North African serpents and the possibly related Scolopendra possessed numerous "feet" and could grow to lengths of 120 feet. There is reason, nevertheless, to believe that both textual and scientific misunderstandings in antiquity led to these remarkable claims and that, in reality, the large North African serpents were only pythons and the Scolopendra a whale. Furthermore, if any credence is given to Oudemans's composite sketch of a modern sea serpent, these ancient creatures cannot fit his model, since Oudemans depicted an animal with a long tail, long neck, small head, and sleek body. Nor do they fit any of Heuvelmans's nine types of sea serpents or any of Ellis's "best documented" cases.

Although this search for sea serpents and land dragons has come up short in the literature of classical antiquity, it has been possible to discern the main factors that turned observations of ordinary (albeit large) snakes and sea creatures into images of frightful monsters. This metamorphosis took place slowly throughout antiquity and continued into the Middle Ages. The chief factors responsible include mismeasurement of sizes, with a tendency to overestimate; relatively poor views of rare animals, with misunderstanding of what had been seen; ignorant conflation of different kinds of animals; willful exaggeration, either to entertain or to frighten; and misreading of earlier textual descriptions. It does not seem necessary to invoke either Carl Jung's notion of vague archetypal images from the "collective unconscious," as Peter Hogarth and Val Clery and also Bernard Heuvelmans have done for monsters generally, or Carl Sagan's more farfetched idea about primitive racial memories of Mesozoic dinosaurs to explain dragons in particular.[41] It is important to remember, as well, that at the same time that the historical transformation of fact into myth was occurring, a more scientific historical tradition—reinforced by accurate new observations—was running parallel to it. The rational was winning out over the irrational.

It is likely that a similar transformation took place during the protohistorical era and that this can explain the earliest serpent myths—at least in part. Yet these very primitive myths of snake-headed monsters (like Typhon and the Gorgon, Echidna, Chimaera, and Hydra) never strayed outside the realm of "old" mythology during the later historical period. The developing "new" serpent myth owes little, or nothing, to Hesiod and other early poets.

[40] E.g., the dog (*Canis familiaris*) developed from the wolf (*C. lupus*) in only several thousand years. On the humid periods see Zhongwei Yan and Nicole Petit-Maire, "The Last 140 ka in the Afro-Asian Arid/Semi-Arid Transitional Zone," *Palaeogeography, Palaeoclimatology, Palaeoecology,* 1994, *110:*217–233.

[41] Hogarth and Clery, *Dragons* (cit. n. 1), pp. 195, 204; Bernard Heuvelmans, "The Metamorphosis of Unknown Animals into Fabulous Beasts and of Fabulous Beasts into Known Animals," *Cryptozoology,* 1990, *9:*1–12; and Carl Sagan, *The Dragons of Eden: Speculations on the Evolution of Human Intelligence* (New York: Random House, 1977), pp. 138–151. David Jones, *Instinct for Dragons* (cit. n. 1) would derive a universal dragon image from our primal fears of snakes, carnivores, and birds of prey. These Jungian notions may well play a role in the "old" mythology, if not the "new."

Even today, the philosophy that guided ancient and medieval writers about exotic beasts flourishes occasionally in modern studies of more recent sightings of unusual animals. Often we find an exaggerated acceptance of older authority and a wishful belief in the marvelous. If the present study does nothing more, it may illustrate the potential for discovering factual truth in an apparent morass of pure fantasy by applying modern scientific and historical methodology.

# UNIDENTIFIED FLYING OBJECTS IN CLASSICAL ANTIQUITY*

*Abstract: A combined historical and scientific approach is applied to ancient reports of what might today be called unidentified flying objects (UFOs). Many conventionally explicable phenomena can be weeded out, leaving a small residue of puzzling reports. These fall neatly into the same categories as modern UFO reports, suggesting that the UFO phenomenon, whatever it may be due to, has not changed much over two millennia.*

Throughout recorded history, reports of what we today might call unidentified flying objects have been made and preserved. If more information were available to us, we would perhaps find that conventional scientific hypotheses could explain most, if not all of these.[1] Certainly this has turned out to be true of most reports from better-documented periods. There nonetheless remains a small residue of puzzling accounts, and regardless of what interpretation one places on them, these constitute a phenomenon that spans centuries of time and widely different cultures.

What may surprise the serious student of the subject is that, despite the numerous articles and books published by scientists on UFOs over the past six decades, almost no scholarly studies of the very early history of the phenomenon have appeared. What little has been accomplished was initiated in 1953 by the astronomer Donald Menzel's naturalistic interpretation of reports in Pliny the Elder's *Natural History*.[2] Menzel's study, however, proved superficial, and had the unfortunate consequence of inducing UFO enthusiasts to compile long, uncritical lists of all kinds of phenomena seen in the ancient skies and call them UFOs.[3] Their methodology was roundly

* I acknowledge an interesting conversation with J. Allen Hynek many years ago, and record also my indebtedness to the Columbia University libraries and the New York Public Library. The final form of this paper owes much to the extensive and critical suggestions of S. Douglas Olson and two anonymous referees.

[1] Mythological and biblical literature has been repeatedly ransacked for evidence of UFOs; see, e.g., Jessup (1956); Le Poer Trench (1960). Skeptical views were first expressed by the astronomer Menzel (1953) 124–34, and the psychologist Jung (1958) 79–84.

[2] Menzel (1953) 118–19.

[3] Wilkins (1954) 163–74; Drake (1977). Other popularizing authors have generally followed, directly or indirectly, Wilkins and Drake.

criticized in the 1968 Condon Report by Samuel Rosenberg, who did not, however, attempt a fresh start by tracking down and analyzing the primary sources themselves. Richard Wittmann, ignoring these authors, produced in 1968 a more scholarly, but also more restricted study of ancient "flying shields." The subject has languished since 1971 and 1975, when Peter Bicknell published two cautious articles in which UFOs were treated only incidentally.[4]

The most liberal attitude would allow that, to an ancient observer, many aerial phenomena were mysterious and hence to some extent unidentified, despite the observer's ability to describe them in familiar subjective terms and despite ancient attempts at theorizing about their nature. Today we can filter out the most obvious cases of conventional phenomena, in spite of the archaic terminology used to describe them. The approach adopted here will be to search for aerial phenomena in the more reliable ancient reports that look like modern UFOs, but without ignoring other manifestations of "strangeness." My working hypothesis will be that most such reports can be explained by conventional scientific ideas and that, among all the reports, only those that defy reasonable interpretation after full analysis can be said to resemble the most puzzling reports made today.[5]

Preliminary screening is relatively easy, thanks to a number of studies of sky phenomena reported in classical antiquity, most famously solar and lunar eclipses, whose reported times and paths can be compared with modern calculations, and comets and new stars (novae), which can be checked against independent observations by Chinese imperial court astronomers. Aurorae too have been inferred from Greek and Roman reports of "chasms," "sky fire," "night suns" and the like; statistical analyses of the times of occurrence of these phenomena during the well-documented interval 223–91 BC show agreement with the modern auroral periodicity of about 11 years, as well as with the modern clustering into two temporal peaks within auroral cycles. Even rare phenomena such as the aerial lights that occasionally accompany earthquakes can be identified in some cases. After large volcanic eruptions, the sun for a few years appears dim, red and sometimes haloed on account of aerosols injected into the stratosphere; these optical phenomena too crop up in ancient reports and can be correlated with modern measurements of aerosol fallout in dated polar ice cores.[6] Mock suns and mock moons have not been

[4] Wittmann (1968); Rosenberg (1969); Bicknell (1971) and (1975).

[5] Modern UFO cases date from 1945–1947, when a wave of sightings triggered a media frenzy. Vallee (1965) has discussed a number of similar cases from the 19th and early 20th centuries; his collection was foreshadowed by the work of Fort (1941).

[6] Eclipses: Ginzel (1899); Boll (1909); Schove and Fletcher (1984); Stephenson (1997). Comets: Gundel (1921); Barrett (1978); Ramsey (2006). New stars: Stothers (1977).

systematically cataloged, but are infrequently recorded and tend to be obvious, owing to their characteristic appearance in pairs. This leaves unusual fireballs, daytime and nighttime disks and the like, and rains of various material, all of which require further analysis.

For presentation purposes, I group the ancient reports in four categories as defined by Hynek for modern UFO sightings (but omitting radar detections), although I have combined Hynek's Nocturnal Lights and Daylight Disks into a single category, which I call Distant Encounters. I have accepted as separate categories his Close Encounters of the First, Second and Third Kinds, which are differentiated according to proximity, material remains and the presence of "occupants."[7]

A brief description of modern UFO sightings may be helpful at this point.[8] Although UFOs vary in morphology and behavior, consistent patterns have emerged. At close range, UFOs appear as disks or other extended objects, including vertical cylinders enveloped in "clouds" and associated with smaller disks. Depending on the viewing angles, their intrinsic shapes might be similar or even identical: a disk seen face-on looks circular, although edge-on it looks elliptical or oblong. Colors in the daytime are usually described as silvery or gray, and in the night as resembling red or multicolored lights. Estimated dimensions range from about one meter to hundreds of meters, with the scatter being probably intrinsic. UFOs are usually said to be noiseless. They are seen in the air or on the ground, hovering or stationary, or moving across the sky in a continuous fashion, even if erratically. Sometimes they suddenly appear or vanish.

*A. Distant Encounters*

Ideally, ancient Distant Encounters would be separated into nighttime and daytime categories, but this is possible in only a few instances. I have instead designated two objective subgroups, depending on whether the objects are described in military language, as types of "flying armaments," or in meteorological and astronomical

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Aurorae: Stothers (1979a) and (1979b); Solow (2005). Earthquake lights: Stothers (2004). Volcanic effects on the atmosphere: Hammer et al. (1980); Stothers and Rampino (1983); Stothers (2002). Scientific methods applied to the ancient prodigy lists are a relatively new weapon in the arsenal of textual controls.

[7] Hynek's (1972) is the only classification system having widespread familiarity, and this is just as well, since Vallee's (1965) earlier system, which he continually refined, is too elaborate for use in the case of the relatively simple ancient reports.

[8] My description summarizes the patterns discerned and discussed by the Vallees (1965), (1966) and (1990); Hynek (1972). A convenient summary of known luminous sky phenomena with which these puzzling cases have been compared can be found at Altschuler (1969).

language, as various kinds of "fiery globes." Within each subgroup the incidents are treated in chronological order.

*Flying Armaments*

Most reports of flying armaments come from Livy's prodigy lists, which for the years preceding *ca.* 123 BC were derived (perhaps indirectly) from the *Annales Maximi* published by the Pontifex Maximus of Rome. In view of the time-consuming and costly procedures required by the Roman authorities to investigate witnesses, verify claims and physical evidence, and expiate the more unusual portents, most modern scholars who have troubled to analyze the prodigy lists have come to regard them as trustworthy and accurate.[9] The unavoidable limitations are that the reporting area is restricted to central Italy, while the number of reports tends to mirror prevailing social conditions; regrettably, the reports are always very terse. The military terminology reflects the most advanced technology known at the time, a tendency found also in modern UFO reports, in which a witness gropes for a familiar technical vocabulary—and perhaps a rationalization—to describe an unaccountable phenomenon. That many reports were made during wartime may partially explain the military terminology.

The following three reports were made under the considerable pressure of the Second Punic War, when prodigies were most likely sought more frequently and carefully than usual. The observers are unknown, but were probably many in number, which may account for the spike in prodigy reports at this time. No compelling reason exists to infer an epidemic of mass hallucination in central Italy, although Livy did note a measure of mass hysteria, and even hysterical contagion, among the populace because of the looming Carthaginian threat.[10]

• At Rome in the winter of 218 BC "a spectacle of ships (*navium*) gleamed in the sky" (Liv. 21.62.4). Franklin Krauss, for lack of an alternative explanation, speculated that the "ships" were clouds or mirages, although suggestive cloud formations had been long-understood, familiar features.[11]

[9] See n. 6, above; Krauss (1930).

[10] It did not escape the shrewd notice of Liv. 21.62.1 and 24.10.6 that the increased number of prodigy reports generated at this time was a sociological consequence of the many reports that had already been made and publicized, as well as a psychological product of fear caused by the war with Carthage. Although Livy voiced skepticism about some of these reports, he did not specify which ones he doubted.

[11] Krauss (1930) 79. Cloud forms when imaginatively interpreted were generally recognized in antiquity to be psychological projections: Ar. *Nu.* 346–57; Lucr. 4.129–42; Cic. *Div.* 2.49; Theophanes Confessor AM 5870.

• In 217 BC "at Arpi round shields (*parmas*) were seen in the sky" (Liv. 22.1.9; Orosius 4.15). A *parma* was a small round shield made partly or wholly of iron, bronze or another metal; we do not know whether the luster of these devices (and not just their shape) was intended to be an element of the description. Mock suns are an unlikely explanation, since in the Roman prodigy lists these were routinely described as "double suns" or "triple suns" (i.e. two mock suns on either side of the real one).

• In 212 BC "at Reate a huge stone (*saxum*) was seen flying about" (Liv. 25.7.8). The implication would seem to be that the object in question was a stony gray color; that it is said to have moved irregularly (*volitare*) leaves open the possibility that the object Livy describes was a bird or some kind of airborne debris.

Sporadic reports of similar objects continue to appear after this in the Roman prodigy lists. The immediate sources are again Livy and his extractors Pliny, Plutarch, Obsequens and Orosius:

• In 173 BC "at Lanuvium a spectacle of a great fleet was said to have been seen in the sky" (Liv. 42.2.4).

• In 154 BC "at Compsa weapons (*arma*) appeared flying in the sky" (Obsequens 17). The term refers to defensive weapons, especially shields.

• In 104 BC "the people of Ameria and Tuder observed weapons in the sky rushing together from east and west, those from the west being routed." Thus Pliny (*Nat.* 2.148) who uses the term *arma*; Obsequens' (43) version is essentially the same. Plutarch (*Mar.* 17.4) calls the weapons "flaming spears and oblong shields," but may be merely glossing and expanding; since he noted the time as night, the phenomenon in question might be the streamers of an aurora borealis.

• In 100 BC, probably at Rome, "a round shield (*clipeus*), burning and emitting sparks, ran across the sky from west to east, at sunset." Thus Pliny (*Nat.* 2.100), although Obsequens (45) called the phenomenon "a circular object, like a round shield." The *clipeus* was a round shield similar to the *parma,* but bigger. Seneca (*Nat.* 1.1.15; 7.20.2), quoting Posidonius (1st century BC), referred to a class of *clipei flagrantes*, saying that they persisted longer than shooting stars.[12]

[12] Possibly related to these are the *disceus* comets, which displayed electrum-colored disks surrounded by scattered rays; see Plin. *Nat.* 2.89; Avienus in Serv. *Aen. ad* 10.272; Campestris in Scholiast to Luc. *ad* 1.529 and in Lyd. *Ost.* 15; Apuleius in Lyd. *Ost.* 10; *Mens.* 4.71; Heph. Astr. 1.24. See also Fuhr (1982) on the Typhon comet, which was twisted like a red coil (Plin. *Nat.* 2.91).

Nothing in the ancient reports forbids that these were spectacular bolides (meteoric fireballs), which move across the sky more slowly than ordinary shooting stars, but enormously faster than genuine comets, which are seen for days or weeks.[13]

• In 43 BC at Rome "a spectacle of defensive and offensive weapons (*armorum telorumque species*) was seen to rise from the earth to the sky with a clashing noise."[14] It might be possible to visualize in this report a bolide exploding while rising above the horizon.

• Historically, the most famous "sky army" appeared in the spring of *ca.* AD 65 over Judea. The historian Josephus reports:

> On the 21st of the month Artemisium, there appeared a miraculous phenomenon, passing belief. Indeed, what I am about to relate would, I imagine, have been deemed a fable, were it not for the narratives of eyewitnesses and the subsequent calamities which deserved to be so signalized. For, before sunset throughout all parts of the country, chariots were seen in the air and armed battalions hurtling through the clouds and encompassing the cities.[15]

Although Josephus probably viewed this phenomenon himself and apparently did research on it, he appeals to eyewitness accounts to bolster his credibility. The phenomenon does not seem to have been an aurora, cloud patterns or meteors, but does resemble the "aerial fighting" of modern UFOs.

*Fiery Globes*

• The first cluster of reports of fiery globes falls during the Second Punic War. Livy reports that in 217 BC "at Capena two moons rose in the daytime ... and at Capua a kind of moon fell during a rainstorm."[16] The Capuan "moon" may have been a manifestation of ball lightning, but the "two moons" at Capena most likely were not. Mock moons are seen only at night when the real moon is very bright, but a bolide seen together with the real moon in the daytime, or a bolide split in two, is a possibility.

[13] For modern bolides, see Nininger (1952).

[14] Obsequens 69; D.C. 47.2.3; possibly also Verg. *Aen.* 8.527–9.

[15] J. *BJ* 6.5.3 (translation by H. Thackeray); Tac. *Hist.* 5.13.2. Silverman (1998) discountenances a rare daytime aurora, which would be quite faint. Compare the military imagery with that in 2 Kings 2:11; Zechariah 6:1–8; Verg. *Aen.* 8.528–9. Other ancient reports of celestial armies seem too vague, illusionary or likely apocryphal to merit discussion: Jason of Cyrene in 2 Maccabees 5:1–4 (cf. 2:21); App. *Mith.* 12.27; Obsequens 56; D.C. 51.17.4; 56.24.3–4; Hdn. 8.3.8–9; Nazarius 10.14.

[16] Liv. 22.1.10–12; Orosius 4.15. Three moons appeared simultaneously in 223 BC and in 122 BC, and probably consisted of two mock moons on either side of the real moon, although the time is not explicitly stated to have been night: Plin. *Nat.* 2.99; Plu. *Marc.* 4.1; Orosius 4.13; Obsequens 32; Apuleius in Lyd. *Ost.* 4; Zonaras 8.20.

• Seneca (*Nat.* 1.1.2; 7.15.1) gives two examples from the eastern Mediterranean. In 168 BC, when L. Aemilius Paullus was waging war against King Perseus of Macedon, "a ball ... was the form of a fire that appeared, as large as the moon." This could have been a bolide.

• A more complicated object made its appearance sometime between 151 and 146 BC:

> After the death of King Demetrius of Syria, ... a little before the Achaean War, a comet blazed out, not inferior to the sun. At first it was a fiery red disk,[17] emitting a light so bright that it dissipated the night. Then, little by little, its size dwindled and its brightness faded; at last the light died completely.

Since the object was seen for more than a moment (as indicated by its designation as a *cometes*), it was probably not ball lightning or a bolide; it also seems to have been too bright to have been the former, and too stationary to have been the latter. Nor could it have been an instance of "night sun" (*sol noctu*), defined by Pliny as creating diffuse light in the nighttime sky and interpreted today as an aurora.[18]

• Two parallel records of 91 BC preserved by Livy's extractors Orosius and Obsequens refer to central Italy.[19] Over the city of Rome "about sunrise a ball of fire shone forth from the northern region with a loud noise in the sky." The sonic boom indicates that this was probably a bolide, rather than ball lightning as Bicknell suggested.

• The same year, a much stranger object was noticed near Spoletium:

> Furthermore, several Romans on a journey saw a gold-colored ball roll down from the sky to the earth; after growing larger, it was seen to rise upward again from the earth toward the rising sun and to block the sun itself by its size.

Bicknell proposed that this was ball lightning. But outside of high-altitude storm clouds, ball lightning averages only 23 cm. in diameter, and the description suggests something much larger than this. Although the reported vertical motion, drawn-out duration and prevailing sunny weather are not unheard-of in ball lightning observations, the combination of improbable characteristics makes this explanation unattractive. The object's apparent trajectory appears more consistent with the approach, overhead passage and retreat of a bolide. On the other hand, an actual landing on or near the ground is strongly indicated.

[17] Contrary to Ramsey (2006) 79–81, the color indicates that it was not a genuine, white comet; see also Sen. *Nat.* 1.15.2.

[18] Plin. *Nat.* 2.100; Stothers (1979a) 94–5.

[19] Orosius 5.18; Obsequens 54. See also Bicknell (1971) 13–16 and (1975) 286–8. Ball lightning is described by Smirnov (1993).

• Pliny (*Nat.* 2.100) also reports an incident that at first glance looks like the preceding one, but occurred at night:

A spark was seen to fall from a star and to grow as it approached the earth; after it had become as large as the moon, light was diffused all around as if on a cloudy day; then, retreating to the sky, the object changed into a torch. This is recorded to have occurred only once: Silanus the proconsul with his retinue saw it, in the consulship of Gnaeus Octavius and Gaius Scribonius.

M. Junius Silanus was governor of the province of Asia in 76 BC, and the incident probably took place there. Silanus' testimony receives indirect support from an allusion by Lydus (*Ost.* 6) to several later occurrences of the same phenomenon, although without reference to a torch. The size, brightness and transience of the object at its maximum seem to rule out a comet or a new star (nova), interpretations suggested by Barrett and Hertzog, respectively. But Bicknell's proposal of ball lightning also founders on the object's change into a torch. Wittmann has postulated a complex UFO encounter, but this explanation seems unnecessary. Since no landing of the object was reported, it is simplest and most natural to interpret the event as the overhead passage of a bolide leaving a luminous train.[20]

• It is not until four centuries later that the next report in this category is found:

At Antioch, in the daytime, a star was seen toward the eastern part of the sky, emitting smoke copiously as if from a furnace, from the third hour to the fifth hour.[21]

This occurred *ca.* AD 334, and was recorded by a Byzantine annalist, Theophanes Confessor, writing five centuries after the event and using unknown sources. The one-day, two-hour duration of the phenomenon is much too short for a comet, despite the suggestions of Barrett, Mango and Scott, and Ramsey, while the smoking trail of a bolide would have appeared most unstarlike, being elongated, irregular, and gradually dissipative.[22]

[20] Wittmann (1968) 225; Bicknell (1971) 14–15 and (1987) 163–4; Barrett (1978) 93–4; Hertzog (1986) 114–15; Huang (1987) 216; Stothers (1987) 211–13.

[21] Theophanes Confessor AM 5826; Barrett (1978) 103; Mango and Scott (1997) 49–50; Ramsey (2006) 173–5. Cf. Revelation 9:1–2. This *astēr* may be the same object as the comet mentioned by Eutropius 10.8 and Aurelius Victor 41 as having appeared before the death of Constantine.

[22] Two other dated reports of mysterious fiery globes are not sufficiently reliable to be worth discussing here: one in 323 BC, Ps.-Callisth. 3.33 (cf. Julius Valerius 3.90); and the other in AD 363, *Epitome De Caesaribus* 43 (cf. Amm. Marc. 25.2.4–8). A fiery pillar appeared near Athens in 404 BC on a moonless, stormy night and was possibly a

*B. Close Encounters of the First Kind*

Hynek defined a Close Encounter of the First Kind as an observation at close range of a UFO that fails to interact with the observer and does not leave a physical trace. By this definition, the "fiery red disk" of *ca.* 150 BC and the "gold-colored ball" of 91 BC might be considered borderline examples.

• A more characteristic example occurred in 74 BC, when a Roman army under L. Licinius Lucullus was about to engage the forces of King Mithridates VI of Pontus. According to Plutarch:

> But presently, ... with no apparent change of weather, but all on a sudden, the sky burst asunder, and a huge, flame-like body was seen to fall between the two armies. In shape, it was most like a wine-jar (*pithōi*), and in color, like molten silver. Both sides were astonished at the sight, and separated. This marvel, as they say, occurred in Phrygia, at a place called Otryae.[23]

The presence of thousands of witnesses, including Lucullus and Mithridates, vouches for the incident's occurrence. The term *pithos* was routinely applied by ancient meteorologists to any large barrel-shaped, smoky celestial fire, according to Posidonius.[24] Could the object of 74 BC have been a meteorite? The bright silvery color might describe the incandescence of the object while falling, but freshly fallen meteorites are black, and Plutarch makes no mention of any noise, let alone an impact. The object must have measured much more than a meter across, since it was easily resolved at a distance greater than half the range of a bowshot. If it had remained on the ground, a meteorite of such size would doubtless have become a cult object in Phrygia, with its long tradition of meteorite worship,[25] yet later historical records referring to Phrygian meteorites are silent about it. In modern experience, an episode like this would easily fall under the rubric of a classic UFO encounter. But we cannot rule out the fall of a bolide.

• A fourth incident is known from a biography of St. Anthony, probably written by Athanasius, bishop of Alexandria, following a personal interview with the witness years afterward. The date was *ca.* AD 285, in or near the Fayûm in the Egyptian desert. Anthony saw

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luminescent tornado: Clem. Al. *Strom.* 1.24 (cf. Exodus 13:21–2; 14:24). Other dated fiery pillars and beams were probably auroral displays: Stothers (1979a).

[23] Plu. *Luc.* 8.5–7 (trans. by B. Perrin).

[24] [Arist.] *Mu.* 395$^b$12; Man. 1.842–3; Sen. *Nat.* 1.14.1; 1.15.2–4; Plin. *Nat.* 2.90; Ptol. *Tetr.* 2.9; Alex. Aphr. *in Mete. ad* 344$^a$5; Origenes *Cels.* 1.58; Arrianus Meteorologicus in Stob. 1.28.2; Phlp. *in Mete. ad* 344$^a$16; Apuleius in Lyd. *Ost.* 10a; *Mens.* 3.41; 4.71.

[25] Cults were associated with several reputed falls of stones in this part of the world, including Troy, Pessinus, Cyzicus, Abydus, Ephesus and Aegospotami.

on the desert floor a large silver disk that suddenly vanished like smoke.[26] Although the encounter is introduced into the biography in a straightforward, factual way, the biography is noted for its religious visions, and even if authentic, the apparition may have been a desert mirage.

*C. Close Encounters of the Second Kind*

In Hynek's system, a Close Encounter of the Second Kind leaves a physical trace. Ancient literature contains no record of a UFO-like object pressing an imprint into the ground or depositing a material residue. On the other hand, rains of strange material were occasionally reported, and since analogous reports in modern UFO research are accepted when sufficiently well-documented and verified, ancient examples are cited here in the absence of more direct evidence. In modern reports, a whitish gossamer substance dubbed "angel hair" is said on rare occasions to have dropped from a UFO and sometimes to have vanished quickly on contact with the ground. In other reports, glassy fibers are left by a UFO after takeoff from the ground, or a chalky substance remains.[27]

• An ancient sample of "angel hair" was perhaps picked up at Rome in AD 196 by the historian Cassius Dio, who writes:

> A fine rain resembling silver descended from a clear sky upon the Forum of Augustus. I did not, it is true, see it as it was falling, but noticed it after it had fallen, and by means of it I plated some bronze coins with silver; they retained the same appearance for three days, but by the fourth day all the substance rubbed on them had disappeared.[28]

Other falls in which a solid whitish substance was involved include two "rains of chalk," one at Cales in 214 BC and another at Rome in 98 BC. No other information is offered about the physical nature of this chalk.[29]

[26] [Athanasius] *Vita Antonii* 11. Mirages were a familiar phenomenon to those living in the North African deserts: D.S. 3.50.4–51.5; Tert. *Adversus Marcionem* 3.24. A desert-dweller like Anthony would certainly have been aware of such an effect.

[27] See the books by the Vallees (1965), (1966) and (1990).

[28] D.C. 75.4.7. The "rain of silver" during Aurelian's reign (AD 270–5), mentioned by Georgius Monachus 3.168, probably alluded to that emperor's reform of the imperial silver coinage, although later annalists interpreted the rain literally.

[29] Liv. 24.10.7; Obsequens 47; August. *C.D.* 3.31. Rains of "wool" were also reported: Liv. 42.2.4; Plin. *Nat.* 2.147; Obsequens 12, 52; Orosius 7.32; Jerome *Chronica* AA 2383; Lyd. *Ost.* 6.

*D. Close Encounters of the Third Kind*

A Close Encounter of the Third Kind involves a UFO seen in association with an occupant, usually described as human or humanoid.

• According to Livy, in 214 BC "at Hadria an altar was seen in the sky; around it were forms of men dressed in shining white." The nature of the altar (*ara*) is not specified. But four years earlier, "in the district of Amiternum, in many places, forms of men dressed in shining white were seen at a distance; they did not approach anyone."[30] Except for this report, entities unassociated with a UFO will not be a subject of investigation here, as problems of identification and verification present insurmountable obstacles even in modern cases, as Hynek and others have shown. The incident of 214 BC nonetheless strikingly recalls the classic observation of UFO occupants on a hovering, overhead craft seen by Father Gill and his companions in 1959 off Papua New Guinea.[31]

• The last encounter is again from the early Christian hagiographical literature and took place near the Via Campana between Rome and Capua *ca.* AD 150. On a sunny day, a "beast" like a piece of pottery (*ceramos*) about 100 feet in size, multicolored on top and shooting out fiery rays, landed in a dust cloud, accompanied by a "maiden" clad in white.[32] There was only one witness to the event, probably Hermas the brother of Pope Pius I.

*Conclusions*

This collection of what might be termed ancient UFO reports has been culled from a much larger number of reports of aerial objects, most of whose identifications with known phenomena are either certain or at least highly probable. Embedded in the mass of relatively explicable ancient reports, however, is a small set of unexplained (or at least not wholly explained) reports from presumably credible witnesses. If these reports are examined statistically, essential features of what I will, for argument's sake, call the ancient UFO phenomenon can be extracted:

• *shape*—discoidal or spheroidal;
• *color*—silvery, golden or red;
• *texture*—metallic or, occasionally, glowing or cloudy;

[30] Liv. 21.62.5; 24.10.10. See also n. 10, above.

[31] Vallee (1965) 145–8; Hynek (1972) 167–72; Herbison-Evans (1977).

[32] [Hermas] *Shepherd of Hermas*, Vision 4.1–3. Cf. Exodus 3:2–6; Job 41:19–21; Jeremiah 1:13; Ezekiel 1:1–28; 3:12–14; 10:1–22; 11:22–4. Hermas' experience resembles the Miracle of Fatima incident in 1917, which Vallee (1965) 148–51 regarded as a classic occupant case.

- *size*—a meter to well over a meter;
- *sound*—usually none reported;
- *type of motion*—hovering, erratic or smooth flight, with a rapid disappearance.

In at least one instance, the presence of "occupants" covered in shiny white clothing is reported. Encounters range from distant views to possibly actual contact; the preferred place and time of observation seem to be rural areas in the daytime. Physical evidence is generally lacking.

Greek and Roman scientific thinkers, who were never at a loss for theories, usually regarded these types of aerial phenomena as stars, clouds, atmospheric fires, light reflections or moving material bodies.[33] Since most of the original theories hark back to Aristotle and his predecessors, with none being later than Posidonius, they generally predate the reports collected here, none of which is earlier than 218 BC. It is accordingly impossible to know whether the later observers (mostly practical Romans) interpreted the phenomena literally as they described them or were simply using the best descriptive language they were capable of, while holding back on theoretical speculation.[34] But any viable theory must reckon with the extraordinary persistence and consistency of the phenomena discussed here over many centuries. Whether one prefers to think in terms of universal recurrent visions from the collective unconscious, misperceptions of ordinary objects, unusual atmospheric effects, unknown physical phenomena or extraterrestrial visitations, what we today would call UFOs possess an intrinsic interest that has transcended the passage of time and the increase of human knowledge.

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[33] Arist. *Mete.* 339$^{a}$33–45$^{a}$10; 370$^{b}$3–78$^{b}$6; Sen. *Nat.* 1, 7; Aëtius 3.2.

[34] At least before the 1st century BC, Greek scientific theory would not have been familiar to many Romans, and so the lack of explicit interpretation in these simple reports should not be deemed surprising.

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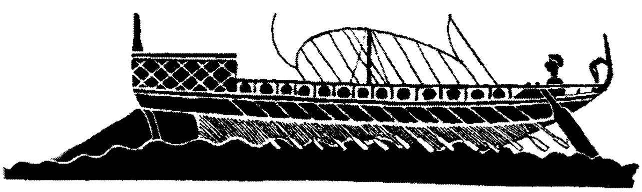

# ANCIENT METEOROLOGICAL OPTICS*

*Abstract: Presocratic, Peripatetic, Epicurean and Stoic theories that aimed to explain Aristotle's four fundamental phenomena of meteorological optics are compared with one another and with modern theories. Notable recorded instances of these and associated phenomena are cataloged. Aristotle's streak, Octavian's halo, Vitellius' antisun and Constantine's and Cyril's crosses are identified.*

Ancient literature abounds in references to the phenomena of meteorological optics. In earliest times, these phenomena were grouped in isolated categories—such as rainbows—and given a mythological or religious interpretation, as in Homer or Genesis 9. After the Ionian Greeks began to speculate scientifically in the 6th century BC, physical theories about rainbows and other meteorological phenomena came into vogue, starting with Anaximenes' doctrine about the rarefaction of air into fire and its condensation into clouds and then water. Anaxagoras and others built on this foundation, but it remained for Aristotle to effectively define the field Plato had called "meteorology" and to offer consistent theories of its divisions, including one containing all the "non-fiery" optical phenomena of the atmosphere.

Aristotle, however, discussed meteorological optics separately from mathematical and physical optics, although he knew the essential links and provided occasional geometrical demonstrations of ray propagation as illustrations of reflection.[1] Consequently, the subject never became mathematical in the way that astronomy, optics, harmonics and statics did. Aristotle and most who followed him combined four fundamental phenomena of meteorological optics under a single umbrella: halo, rainbow, mock sun and streak. Although the common denominator in Aristotle's comprehensive theoretical explanation was reflection from a moist cloud, his concept of reflection was not universally accepted.

A number of modern authors have traced the development of ancient meteorological optics, focusing primarily on how the ancients explained the phenomena and less on comparisons with modern observations and theories. Some of these comparisons in the

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[1] Arist. *APo.* 79a10–13, 98a26–9; *Ph.* 194a8–12; *Mete.* 3. Fiery (i.e., real) and nonfiery (i.e., illusionary) optical phenomena were first formally differentiated by Posidonius; see Waiblinger (1977) 27.

older studies are now out of date. Furthermore, modern authors have concentrated on the rainbow (as did the ancients) with less attention directed to the other phenomena. Finally, all authors have essentially ignored the specific instances recorded as prodigies and portents in antiquity.[2]

In order to not cover ground already adequately trodden, my focus will be on the halo, mock sun and streak, along with two closely allied phenomena, the light cross and mock moon, which were not discussed by Aristotle. Unlike the rainbow, these are all parhelic and paraselenic phenomena of the upper atmosphere, and so form a natural physical group in today's understanding of such phenomena. To orient the reader, a synopsis of modern meteorological optics is presented first in a non-technical format. The ancient theories follow, with the rainbow included for necessary comparison. Finally, the specifically reported optical displays with historical interest are collected and discussed.

*A. Primer of Meteorological Optics*

The atmosphere is conventionally divided into three parts: a lower part called the *troposphere*, where our ordinary turbulent weather and clouds occur; a middle part called the *stratosphere*, where tiny particles of dust remain quietly suspended for years; and a tenuous upper part, which does not concern us here. Within the troposphere, the higher layers are very cold, and ice crystals form in them, creating cirrus clouds. Occasionally, when a violent volcanic eruption thrusts its ejecta far aloft, the stratosphere becomes filled with very fine particles composed of silicate ash and sulfate aerosols. Although the heavier ash falls out quickly, the aerosols can survive for several months to a few years.

The particles that cause the peculiar optical effects thus occupy characteristic parts of the atmosphere. Water droplets occur in the lower layers of the troposphere. When sunshine penetrates a water droplet, the rays are first refracted at the surface, then reflected from the backside and finally refracted again on leaving the surface. This causes a *rainbow* to appear opposite the sun for any observer. Ice crystals and volcanic dust, higher in the atmosphere, diffract the sun's light and create what is known as a *corona* or *aureole* around the sun. The corona due to volcanic dust is called a Bishop's ring.[3] Rain-

[2] The most important work on the subject is Ideler (1832) 180–99; Gilbert (1907) 600–18; Boyer (1959) 33–73; Böker (1962) 1663–92; Taub (2003) 71–164. See also the brief account by Blay (1995) 14–20. My general approach to the subject is like that of most of these authors, in that I do not attempt to place meteorological optics within the larger picture of ancient science. My discussion sets it instead in the context of its time, lists ancient instances of the phenomena and discusses them in the light of modern knowledge. Since science is cumulative and never definitive, and observational data remain valuable, this practical approach using a modern viewpoint has its place.

[3] First described by Bishop (1884) after the Krakatau eruption of 1883.

bows and diffraction coronae are red on the outside and blue on the inside of their arcs. But ice crystals can also refract light, in which case they form a circular *halo* around the sun. Radial spokes and tangent arcs occasionally accompany the halo, creating an irregular appearance. A refraction halo differs from a diffraction corona in being blue on the outside and red on the inside.[4] All these particles also reflect light to some extent. In this case, the reflected light remains colorless (that is, white) if the unobscured sun is the source of it.

Refraction from ice crystals can sometimes produce a white *light pillar* rising above and extending below the sun. At the high point where the pillar intersects the halo, another light enhancement, called the *vertical parhelion*, may occur. The light pillar is often accompanied by a horizontal crossbar, another reflection effect. The combined pillar and crossbar yield a *light cross*, centered on the sun. Thus whenever the halo is invisible, only the cross of light appears.[5]

A full display of the optical effects produced by the rising and setting sun can be very impressive. Especially when the sun lies close to the horizon, it generates a faintly visible circle around the whole horizon at the same elevation, called the *parhelic circle*. In the antisolar position, a weak luminous patch may occur, the so-called *anthelion*. Both the parhelic circle and the anthelion appear white because they are caused by reflected sunlight. The multicolored refraction halo around the sun intersects the white parhelic circle at two points, situated about 22° north and south of the sun. At these points, enhancements of light occur, commonly designated *mock suns*, *sundogs* or *parhelia*. Sometimes only one parhelion appears, while on rare occasions a second halo (or even a diffraction corona) of radius 46° can be seen, accompanied by its own parhelia. Like the refraction halo from which it is formed, a parhelion at 22° is red on the side facing the sun. A mock sun can be exceedingly bright, sometimes as bright as the real sun, in which case it appears entirely white and colorless. Even rarer phenomena have been reported, but these need not be discussed here.[6]

[4] Humphreys (1940) 476, 512, 552, 555; Minnaert (1940) 172, 192, 214, 282. Color photographs of these phenomena appear at Greenler (1980); Meinel and Meinel (1983); Lynch and Livingston (1995). Refraction is the bending of light rays as they pass through a partly transparent medium, whereas diffraction is the bending of light waves around an opaque object; the scattering of the white light disperses the light into a spectrum. These phenomena are most simply described by geometrical optics—an idealization that nevertheless does not really account for diffraction. All of them, however, should be consequences of Maxwell's laws of electromagnetism.

[5] Vertical parhelion: Humphreys (1940) 536, 544. Light cross: Humphreys (1940) 543–5; Minnaert (1940) 201–3. Photograph of light cross: Fiorino (2007) 37.

[6] General discussions: Humphreys (1940) 501–45; Minnaert (1940) 190–204. Photographs as follows. Parhelic circle: Fiorino (2007) 37. Anthelion: Humphreys (1940) 538. Double halo: Lynch and Livingston (1995) 157. Mock sun: Fiorino (2007) 37.

Similar optical features are associated with the moon. Rainbows, coronae, haloes, light crosses and mock moons (also called *moondogs* and *paraselenae*) are seen when the moon is very bright, at or near full.[7] Owing to the general faintness of moonlight, however, more complex phenomena are rarely observed. Faint coronae can also be observed around the brighter planets and stars.

*B. Ancient Theories*

Which among the phenomena of meteorological optics first received theoretical attention in antiquity is unknown. Although the rainbow is attested first, Aristotle himself discussed the halo before the rainbow in his *Meteorologica* because this arrangement suited his theoretical requirements. Since we are not constrained by Aristotle's pedagogical considerations, I follow the probable chronological order. To simplify the discussion, no exposition of ancient theories of vision is included, since the basic physics of the meteorological phenomena remains the same whether the line of sight proceeds from the eye to the object or vice versa. In the *Meteorologica* (but not elsewhere) Aristotle adopted an extromission theory of vision.

*Rainbow*

Greek writers called the rainbow *iris* or (rarely) *toxon*, while Latin writers referred to it as *arcus*. Although speculation about the origin of the rainbow goes back to early myths, Anaximenes' explanation is the first scientific one of which we have a record. He believed that the rainbow is generated by the sun's white rays of light falling on an impenetrably thick, dark cloud; the mixture of white and black produces the other colors. This view influenced all subsequent work throughout classical antiquity. Among known pre-Aristotelian thinkers, Xenophanes, Anaxagoras and Metrodorus of Chios accepted Anaximenes' idea. In particular, Anaxagoras added the important concept of reflection of the sunlight from the thick cloud as if from a mirror. Metrodorus believed that the sunshine brought out a blue color in the cloud and reddened the sunlight at its edges.[8] Although the problem of the curvature of the rainbow is not addressed in our sources, Boyer has reasonably concluded that the Presocratics envisaged a cloud of spherical shape.[9]

Aristotle presented the first detailed model, consisting of a thick cloud composed of dense air beginning to turn into water. The partially formed water droplets act as tiny mirrors that reflect color, because they are very small, but not shape, which only a large mirror can do. Nevertheless, the aggregate of water droplets behaves like a

[7] A painting by L. Wenckebach that shows many of these lunar phenomena in a full display is reproduced at Minnaert (1940) plate IX(b).

[8] Anaximen.: Aët. 3.5; Hippol. *Haer*. 1.6; Scholiast to Arat. 940. Xenoph.: 21 B 32 D–K. Anaxag.: Aët. 3.5; 59 B 19 D–K. Metrod. Chios: Aët. 3.5; Scholiast to Arat. 940.

[9] Boyer (1959) 42, 57.

smooth surface. Water, being dark, reflects a red color—hence the red on the outside edge of the rainbow arc. The green and blue are due to an even darker reflection on the inside edge. Yellow is an illusionary appearance due to contrast. The rainbow displays a relatively short arc because it lies far from the illuminating sun, in a direction opposite the viewer. Aristotle provided a geometrical demonstration of this relative positioning. He was aware of double rainbows and of rare lunar rainbows. He most likely knew the law of equal angles of incidence and reflection in the phenomenon of reflection from a plane surface. He also gave examples of refraction in air and water from familiar terrestrial situations, but did not apply this knowledge to a meteorological explanation of the rainbow and related phenomena. These he treated together as manifestations of reflection from a dense cloud containing different ratios of water and air.[10]

Most known post-Aristotelian authorities, including the founder of the Stoic school, Zeno of Citium, accepted Aristotle's theory of the rainbow, although with different emphases, minor variations and embellishments. Epicurus, in a typically contrarian way, agreed that the rainbow might be colored and shaped in the Aristotelian fashion, but then suggested that light might instead mix with air to produce colors in the air by some kind of reflection, while the circularity of the rainbow might come about if there were reflecting atoms (rather than Aristotle's water droplets) in the air or in the cloud and if they had emanated from the sun, which is round.[11] Posidonius and certain other Stoics, including apparently Artemidorus of Parium, argued that the rainbow arises because the sun's light bounces off a smooth, concave, mirror-like cloud. In Seneca's view, these Stoics were wrong to think that the cloud, which resembles a ball cut in half, reflects only a small segment of the sun rather than the whole solar image.[12] Although Seneca's own views are more like Aristotle's than like those of his fellow Stoics, in that he emphasized the reflecting properties of the water droplets forming the rainbow, he seems to have regarded the rainbow arc as the magnified image of the sun's circular shape, and confused the phenomena of reflection and refraction, thinking the latter to be a manifestation of the former. Finally, he believed that rainbows are prognosticators of weather—a very old idea, although Pliny doubted its validity.[13]

[10] Arist. *Mete*. $371^{b}18$–$7^{a}28$; Sen. *Nat.* 1.3.5–8; Aët. 3.5; Scholiast to Arat. 940; Alex. Aphr. *in Mete*. *ad loc*.; Stob. 1.30; Olymp. *in Mete*. *ad loc*. A contemporary of Aristotle belonging to Plato's circle, Philip of Opus, supported the analogy of a mirror by noticing that the rainbow appears to follow the moving viewer (Alex. Aphr. *ad* $373^{b}32$).

[11] D.L. 10.109–10. Lucr. 6.524–6 gives only Epicurus' first (Aristotelian) explanation.

[12] [Arist.] *Mu*. $395^{a}29$–35; Sen. *Nat*. 1.4.1–4, 1.5.10–13, 1.8.4; Plu. *Mor*. 358f–9a; 765e–f; 921a; 937b; D.L. 7.152. The passage in pseudo-Aristotle reappears practically *verbatim* in Diogenes Laertius. Plin. *Nat*. 2.150 accepts the Stoic theory, but doubts that lunar rainbows occur, despite Aristotle, Posidonius and Seneca.

[13] Sen. *Nat*. 1.3.9, 1.4.1, 1.5.13, 1.6.5–6, 1.8.8; Plin. *Nat*. 2.150.

Seneca (*Nat.* 1.3.1–4) also discussed two other previously proposed explanations of the rainbow, without naming his sources. Perhaps these explanations were Epicurean but shorn of the objectionable atoms. One explanation is that the sun's rays illuminate an inhomogeneous cloud in such a way that the unevenness of the cloud's density produces light and shadow. Since it was often theorized in antiquity (for example, by Anaximenes) that all colors arise from a mixture of white and black, a rainbow will result. A second explanation is that the cloud contains a mixture of droplets of varying density, the less dense of which transmit sunlight and so are bright, while the more dense cast shadow. The mixture of types produces the rainbow's colors. Seneca thought of the cloud itself as having an intrinsic color (1.3.12–13, 1.5.11). Yet when the cloud is struck by sunlight, its water droplets yield all the colors, since bright light and dark light produce different colors. Although ancient authors recognized different primary colors of the rainbow, these apparent differences arise from subjective perceptions of the rainbow's true colors.

The late commentators Alexander of Aphrodisias and Olympiodorus the Younger elaborated on Aristotle's theory of the rainbow but added little new. Alexander did, however, note the darkness of the intermediate band that separates an outer rainbow from an inner one. We know from these authors, as well as from Seneca, that other writers seriously discussed refraction as a possible explanation of the rainbow, but details are lacking.[14]

*Halo*

A ring around the sun was designated by Greek writers as a *halôs*, *stephanos*, *iris* or (once) *kuklos*, while Latin authors wrote *corona*, *circulus*, *arcus*, *orbis*, *ambitus* or (once) *area*.[15] The word *halôs* means literally a threshing-floor, which was often circular in shape; it was accordingly translated into Latin as *area* (Sen. *Nat.* 1.2.3). Since no distinction seems to have been made among these terms, I have simply translated them all with the generic English "halo." Few ancient reports permit us to discriminate between the oppositely colored "refraction halo" and "diffraction corona," except occasionally when we can associate Bishop's ring with a volcanic eruption. Otherwise, the ancient likening of an observed "halo" to a rainbow implies only that some dispersion of colors was noticed.

[14] For a thorough discussion of Aristotle's reflection theory and of Alexander's and Olympiodorus' defenses of it, see Boyer (1959) 33–73. Boyer's lengthy discussion of the ancient rainbow remains valuable, but he can be inaccurate in places, depends occasionally on modern authorities as primary sources, and has some unexpected omissions (e.g., Epicurus).

[15] Arat. 796 initially uses *kuklos*, but follows this with *alôê* (*halôs*). Kidd (1997) 450–1, in spite of the explicit testimony of the scholia, Ach. Tat. 34 and Avienius 1484, insists that Aratus applied *kuklos* to the moon's disk rather than to a halo.

Aristotle noted that haloes are commonly seen around the sun, moon and bright stars. To him, a halo is the reflection of our vision off a large, uniform cloud of air and uncondensed water vapor, broken up into small parts that act like tiny mirrors. When the cloud surrounds its luminary evenly on all sides, the halo appears circular. But it is only weakly colored, or even uncolored, because the vapor has not yet turned into water and the luminary is very near. Aristotle's geometrical demonstration of the halo's circular shape, however, merely assumes what it sets out to prove, and he does not differentiate what we would call a "refraction halo" and a "diffraction corona" with their different spatial orderings of colors. The halo is always observed near but not too close to its luminary, because the luminary's heat dissolves the nearest parts of the cloud, while our vision becomes too weak if it has to travel far to reach the object. A dark halo around the sun or moon prognosticates rain, unless the halo is fading while still unbroken, in which case it is a harbinger of fair weather. If the halo is broken anywhere, it indicates wind from the quarter in which the break occurs.[16]

Epicurus is known to have discussed at least the lunar halo. In his theory, the moon's light reflects off the surrounding air, thereby forming the halo. Unlike Aristotle, Epicurus believed that the reflecting layer of air does not lie beneath the moon, surrounding it only in appearance, but that the body of air physically extends all the way up to the moon. We may conjecture that his theory of the solar halo would have followed suit, the sun being, in his empiricist view, only as large as it appears, namely about a foot wide! Posidonius, Seneca, Alexander of Aphrodisias and Alexander's teacher, Sosigenes, on the other hand, all accepted Aristotle's sublunary reflection theory. They were nearly alone; Alexander remarked that most other authorities ascribed the halo to refraction rather than reflection. Who these other thinkers are and what their arguments were is unknown.[17]

Seneca (*Nat.* 1.2, 1.10) provided a dynamic model for the halo that is different from Aristotle's static model. The rays of the sun or moon, he argues, strike and compress the air in a uniform way whenever the air is motionless.[18] Since the luminous source is spheri-

[16] Arist. *Mete.* $371^{b}18$–26, $372^{b}12$–$3^{a}31$, $374^{a}11$–16; *Pr.* 15.12; Plin. *Nat.* 2.98; Alex. Aphr. *in Mete. ad loc.*; Stob. 1.30; Olymp. *in Mete. ad loc.* Weather prognostications later than Aristotle: [Thphr.] *Sign.* 22, 31, 51; Arat. 796–8, 811–17, 877–9 (with scholium), 941; Gem. 17.47; Ph. *On Providence* 2.47; Sen. *Nat.* 1.2; Plin. *Nat.* 18.344–9; Ptol. *Tetr.* 2.9, 2.13; Basil *Hexameron* 6.4; *Gp.* 1.3. Aratus states that two or three haloes presage even worse weather than one does; the redder or darker the halo, the worse the storm.

[17] Epicur. in D.L. 10.110–11; [Arist.] *Mu.* $395^{b}1$–3; Sen. *Nat.* 1.2; Alex. Aphr. *in Mete. ad* $372^{b}34$.

[18] Taub (2003) 164 considers that Theophrastus and Seneca, unlike Aristotle, thought of lunar haloes "as materially constituted, and not as optical phenomena." The slight evidence from Theophrastus (*Meteorologia*) is inconclusive, but Seneca clearly views the halo as an optical reflection of the luminary's light from a spherically

cal and the atmosphere is still, the halo too must be round, just as a pebble thrown into a fishpond creates many little circles in the water. Solar haloes are less common than lunar ones because the sun's light is often strong enough to disperse the thin daytime air. Starlight, on the other hand, is too feeble to form haloes around any but the brightest stars. Seneca perceived the halo basically as a complete, circular rainbow. Therefore, like Aristotle, he must have failed to note the reversed order of colors in what we would call a "refraction halo." Finally, Olympiodorus (*in Mete*. *ad* $372^b18$) seems to have been the first to measure the halo's diameter, which he gave nearly correctly as 40°.

*Mock Sun*

Classical authors usually refer to a mock sun as a second *hêlios* or a second *sol*. Instances of two mock suns accompanying the real one are reported about as often as a single mock sun. Pliny (*Nat*. 2.99) states that more than three "suns" (two mock suns and the real sun) had never been recorded up to his time. A mock sun is also designated by pedagogical and technical authors as a *parêlion* or *anthêlion* owing to its sky position and brilliance.[19]

Anaxagoras explained the mock sun as he did the rainbow, as a mirrorlike reflection from a dense cloud. Aristotle added his own details. The mock sun is simply a strong reflection from a homogeneous, watery cloud. Since this type of cloud looks like a large uniform mirror and the cloud must be located close to the sun, the powerful reflection shows a single color—that of the real sun, white. A mock sun always appears to the side of the real one and usually around the time of sunrise or sunset. It does not occur above or below the sun or in the opposite quarter of the sky, for reasons like those given for the halo. Since the ambient air is saturated with water when a mock sun forms, the phenomenon always presages rain.[20]

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compressed mass of air; to him the halo is thus not a "real" material phenomenon like a substance emitting fire.

[19] The less common word *anthêlion* was employed by the Scholiast to Arat. 881, Cleom. 2.6.10, Aët. 3.6, Basil *Hexameron* 6.4 and others, although an ordinary mock sun is clearly being referred to. See Böker (1962) 1682–4; Goulet (1980) 5. Unaccountably, Böker treats the *clipeus* and *disceus* "comets" (Sen. *Nat.* 7.20.2; Plin. *Nat.* 2.89, 2.100) as mock suns; they are most likely meteoritic bolides. He also interprets other kinds of "comets" (because Aristotle did?) as purely meteorological phenomena; most seem to be genuine comets. Kidd (1988) 469 and Bowen and Todd (2004) 162 wrongly interpret the ancients' *anthêlion* as the modern anthelion.

[20] Anaxag. in Aët. 3.5; Arist. *Mete*. $371^b18$–20, $372^a10$–21, $377^a29$–$8^a14$; *Pr*. 15.12; Plin. *Nat.* 2.99; Alex. Aphr. *in Mete. ad loc.*; Prud. *Origin of Sin* 85–8; Stob. 1.30; Olymp. *in Mete*. *ad loc.*; Lyd. *Ost*. 4. Weather prognostications later than Aristotle: [Thphr.] *Sign*. 22, 29; *Vent*. 36; Arat. 880–9; Sen. *Nat*. 1.13; Ptol. *Tetr*. 2.9; Basil *Hexameron* 6.4. Aratus says that two red mock suns presage a wintry storm; if there is only one of them and it lies to the north, a north wind will blow; and if only one of them occurs, to the south, rain will arrive from that direction.

Sporus (3rd century BC) and Posidonius seem to have mostly accepted Aristotle's theory of the mock sun, but they explicitly assumed a spherical cloud and emphasized its extreme whiteness due to its following the sun so closely. Although Strabo thought that a mock sun must be strongly heated by the sun's rays, the scholiast to Aratus 880–9 says that if the cloud is whipped by a cold wind, it freezes into solid ice and as a consequence of its higher density appears red when receiving the solar rays. Only Aratus claims that a mock sun must appear red in order to serve as a weather sign.

Seneca discussed multiple mock suns. Because clouds cannot receive a clear image of the sun if they are in motion, thin or filled with impurities, only one or two clouds at any time are likely to have enough coherence and density to reflect a good image of the sun. If there are two such clouds, one will reflect a secondary image from the other, yielding a pair of mock suns. Cleomedes later conjectured that a mock sun might be able to form above the sun after sunset, since the air near the horizon is both dense and moist. Ammianus Marcellinus, on the other hand, believed that a mock sun had to be a cloud lying very high up in the atmosphere, in close physical proximity to the sun. Different interpretations were possible because Aristotle was unclear about the vertical distance at which mock suns form.[21]

*Streak*

Aristotle associated the so-called streak or rod (*rhabdos*, Latin *virga*) with the halo, rainbow and mock sun in a common origin, but specifically with the mock sun in its physical development. The streak appears to the side of the sun around sunrise or sunset. It is caused by light reflection from an inhomogeneous cloud, in contrast to the homogenous cloud that leads to a mock sun. The small inhomogeneities reflect the colors of the sun and not its shape, and so the manifestation is a kind of "straight rainbow" rather than a white circular patch. As in the case of the mock sun, the streak cannot develop very close to or very far from the sun. Also like a mock sun, it portends rain, especially when it occurs south of the sun.

Aristotle's views were endorsed and reproduced by the anonymous authors of *De mundo* and *De signis*, as well as by Seneca, Aëtius, Ptolemy, Alexander of Aphrodisias, Basil, Stobaeus and Olympiodorus.[22] According to Seneca (*Nat*. 1.11.1), another class of streak looks like a bundle of thin rays extending through narrow openings in the clouds. Seneca's description thus implies that the

[21] Posidonius and Sporus in Scholiast to Arat. 881; Str. 7.3.18; Sen. *Nat.* 1.11–13; Cleom. 2.6.10; Amm. 20.3.6. Aristotle's confusing stratification of the sublunary sky has been deciphered by Lee (1952) 24–7, 243, 250–1; as well as by Seneca (*Nat.* 2.10), as Williams (2005) 155 has noted.

[22] Arist. *Mete*. 371b19, 372a10–14, 374a16–18, 377a27–8a11; [Arist.] *Mu*. 395a29–36; [Thphr.] *Sign*. 11; Sen. *Nat.* 1.9–10; Aët. 3.6; Ptol. *Tetr*. 2.9; Alex. Aphr. *in Mete*. *ad loc.*; Basil *Hexameron* 6.4; Stob. 1.30; Olymp. *in Mete*. *ad loc.*

term “streak” came in time to be employed more broadly than in Aristotle. The original sources used by Aristotle are unknown, although the offhand way in which he introduces *rhabdos* suggests that the word was already familiar as a meteorological term.

Modern authors such as Carl Boyer and Robert Böker agree with Otto Gilbert in interpreting Aristotle’s streak as a watergall (or weathergall), which is simply the truncated lower portion of a rainbow, while Jules Tricot and Liba Taub regard the term as referring to a luminous column rising above the sun. Aristotle, however, placed the streak close to the sun not opposite it, and to the side of the sun, not above it. David Sider and Carl Brunschön suggested that a streak is a light pillar extending above and below a mock sun, but the rainbow colors are then difficult to understand. More credible is Paul Oltramare’s suggestion of a long horizontal band, the parhelic circle. But this circle is white, not colored like a rainbow. Pierre Louis has conceived of a patch of oblong striations having the colors of a rainbow, but his reworking of Aristotle’s description does not identify the streak. I suggest that the streak is simply a multicolored mock sun. Whenever a mock sun is not formed in the shape of a circle, it can display a coarse, diamond shape with edges colored like a rainbow. In its purest form, the whole object looks like a small, rectilinear rainbow.[23]

*C. Specific Appearances*

Some phenomena such as rainbows and lunar haloes are so frequently seen that they are not reported in ancient literature as special prodigies even though they were usually regarded as weather signs. Other phenomena, not so common, include solar haloes, mock suns and light crosses. Whenever they are recorded, they must have been either strikingly conspicuous owing to an extremely unusual atmospheric condition or ominously associated with an important event. The rarest phenomena of all, such as bright mock moons, must have been infrequently noticed.

*Solar Haloes*

Haloes surrounding the sun were recorded in antiquity in conformity with these expectations. Surviving reports are summarized in Table 1. The rainbow-like haloes of 121 and 44 BC were almost certainly Bishop’s rings due to eruptions of Mount Etna in 122 and 44 BC.[24] But it was Octavian’s entry into Rome in 44 BC that made his

[23] Gilbert (1907) 617; Tricot (1941) 185; Boyer (1959) 25; Böker (1962) 1684–5; Oltramare (1973) 37; Louis (1982) 6; Taub (2003) 78. The pure, rainbow-like mock sun is illustrated at Lynch and Livingston (1995) 162, and imperfectly at Fiorino (2007) 37. The second type of streak in Seneca’s description, if it too is colored like a rainbow, may be a cirrus-cloud display viewed through breaks in cumulus clouds, as illustrated at Gonnelli (2008) 12.

[24] Stothers and Rampino (1983) 6359. The halo of 44 BC has been dated with greater precision to the early part of May by Ramsey and Licht (1997) 101.

solar halo so memorable, because it appeared to encircle him like a kind of crown. The four other early reports of haloes might also be traceable to volcanic eruptions, but we do not know for certain. Since all these reports are found in the annual Roman prodigy lists, no special historical event need be attached to them. The haloes of 203 and 147 BC are noteworthy for having been visibly double.[25] The object of 203 BC consisted of a thin, rainbow-like inner halo and a wide outer halo of unspecified color, while the object of 147 BC was described simply as composed of a red halo and a white halo. The single halo of 90 BC also was red. No details are given for the halo of 114 BC.

Philostratus relates that a halo (*stephanos*) colored like a rainbow was seen in Greece by many people, including the provincial governor, ca. AD 94. Although his report appears in a biography of Apollonius of Tyana and he has chosen his meteorological terminology in clear allusion to the name of the emperor Domitian's assassin, Stephanus, there is no good reason to reject the report. By contrast, the biographer of Severus Alexander in the *Historia Augusta* says that among the many omens attending Alexander's birth in AD 208 was a halo surrounding the sun; even if authentic, this halo need not have been otherwise remarkable. Nor are any details known about the halo observed in AD 270, probably at Alexandria, which was later speculatively linked to the death of Claudius Gothicus at Sirmium.

*Light Crosses*

It is surely significant that our earliest surviving record of a light cross (*stauros*, *crux*) harks from the Christian era. But appearances of this type must have been noticed in previous centuries.

The luminous cross reported to Eusebius by Constantine the Great as having appeared to him and his army early in AD 312—almost certainly in Italy—has been attributed by modern scholars to a formation of clouds, shafts of sunlight, lightning or a parhelic display. There is no compelling reason to doubt Eusebius' account, which was quoted by many later authors. The reported location of the cross, "situated over the sun" (*huperkeimenon tou hêliou*), suggests a parhelic light cross.[26]

Very different circumstances are recorded for the luminous cross that appeared to many people in Jerusalem on 7 May, probably in AD 351.[27] According to St. Cyril, patriarch of Jerusalem, who was an eyewitness, the cross extended from Mount Calvary to the Mount of Olives in the eastern sky and appeared brighter than the sun. Philostorgius and the *Chronicon Paschale* mention that it was surrounded

[25] The double halo of 203 BC appeared during a period of suspected activity of local Italian volcanoes—specifically Vesuvius—extending from 217 BC: Stothers and Rampino (1983) 6360; Stothers (2002); to 202 BC: Krauss (1930) 69.

[26] Ideler (1836) 320–1 and Jones (1948) 95–6 likewise favor a light cross.

[27] Ramsey (2006) 207–11.

by a rainbow-like halo. Many other chroniclers report the cross, but not always the halo. This phenomenon illustrates what is probably the full development of a solar refraction halo enclosing a brilliant light pillar transected by the parhelic circle.[28]

*Mock Suns*

Euripides in his *Bacchae* has Pentheus claim to see two suns. Pentheus is insane, and also perceives two cities of Thebes.[29] Nonetheless, Euripides' mention of two suns may be rooted in the already well-known phenomenon of the mock sun. For example, John Lydus (*Ost*. 4) relates from an unknown source that an apparent doubling of the sun was observed when Cambyses invaded Egypt in 525 BC. Aristotle in his discussion of mock suns mentions that two suns once accompanied the real sun all day long in the Bosporus.[30] They were also said to be commonly seen in Pontus.[31]

A series of eight recorded instances of double or triple suns appear in the Roman prodigy lists, as summarized in Table 2. All these manifestations were reported at Rome or elsewhere in central Italy during the period 206–104 BC, except for one in Gaul in 122 BC.[32] Another five reports were made at Rome between 44 BC and AD 193 in connection with later, obviously important historical events. In the immediate aftermath of Caesar's assassination in 44 BC, a display of three suns appeared on two occasions. The first display occurred in 44 BC itself and involved a spiky halo surrounding the "lowest sun" (*solem imum*)—presumably the central, or real sun. The second display occurred in 42 BC, but no details are known.[33] Claudius' fifth consulship in AD 51 also witnessed three suns. Somewhat later, if Cassius Dio is to be believed, two suns in AD 69 portended Vitellius'

[28] Ezekiel (1; 3; 10; 11), who was living near Babylon ca. 593 BC, saw visions of wheels accompanied by strange animal figures in the sky. Although the whole context of his account as well as specific passages (1:1; 8:1–4; 10:22; 11:24; 40:1–2) suggest vivid dreams, possibly in a trance state, Menzel (1953) 125–34 interprets his visions as observations of a full parhelic display, the wheels being bright solar haloes and the animal figures being light pillars and crosses. Silverman (2006) prefers an auroral interpretation.

[29] E. *Ba*. 918–19; V. *Aen*. 4.469–70; Plu. *Mor*. 1083e–f; Clem. Al. *Protr*. 12; *Paed*. 2.24; Serv. *Aen*. *ad* 4.470; Nonn. 46.125.

[30] Arist. *Mete*. 372$^{a}$14–16; Str. 7.3.18; Plin. *Nat*. 2.99; Alex. Aphr. *in Mete*. *ad loc*.

[31] Anaxag. in Aët. 3.5; Cleom. 2.6.10.

[32] Rawson (1971) 160–1 points out that repetitions of prodigies, referred to as doublets, crop up occasionally in the Roman prodigy lists for different (but neighboring) years. Three doublets occur in Livy's lists for 206 and 204 BC (28.11.2–4; 29.14.3). Among them is a doublet of *duo soles*, to which I have assigned the year 206. The *duo soles* of 166 and 163 BC also may be a doublet. Ramsey (2006) 194 takes the second *sol* of 163 BC to have been a comet, under the mistaken belief that mock suns must always appear in pairs. Krauss (1930) 72 argues that the two daytime "moons" of 217 BC at Capena (Liv. 22.1.10) were faint mock suns. Finally, Kidd (1988) 468 appears to have mistaken the general phenomenon of "three suns" for three mock suns.

[33] Although Eus.-Jerome *Chronicle* Olymp. 184 seems to refer to the instance of "three suns" in 44 BC, comparison with Obseq. 68 and 70 shows that the apparition of 42 BC is meant.

death; the one in the west was pale, while the one in the east was bright. Since Dio is alluding to Vitellius in Rome and Vespasian in Judea, "west" and "east" almost certainly mean a separation of 180º, in which case the pale western sun represents the only mention of an anthelion in classical literature.[34]

Dio and a crowd of Roman observers saw three "stars" (*asteres*) surrounding the sun shortly before the death of Didius Julianus on 1 June, AD 193.[35] These "stars" were immediately associated with the three imperial contenders Severus, Niger and Albinus. The apparition likely consisted of two mock suns and a vertical parherlion, although the occurrence of a triple solar halo cannot be ruled out.

*Mock Moons*

Only two or three instances of possible mock moons (*luna*, *selênê*) occur in classical literature. The old Roman prodigy lists report "three moons" during the nighttime at Ariminum in 223 BC and "three moons" at an unknown hour in Gaul in 122 BC. The "two moons" in the daytime at Capena in 217 BC were almost certainly not the real moon and a mock moon, because the daytime moon would not shine brightly enough to generate a noticeable paraselene.[36]

*Conclusions*

All the major phenomena of meteorological optics scientifically recognized today were noticed and recorded in classical antiquity. In addition to the well-known rainbow, mock sun, and solar and lunar haloes, I have identified at least two Bishop's rings, an anthelion, two mock moons and two light crosses. Aristotle's streak was almost certainly a rainbow-like mock sun. What ancient researchers lacked was an adequate theory of these phenomena. Although the rarest phenomena attracted so little attention that no theory was proposed for them, the basic meteorological tetrad of antiquity—rainbow, halo, mock sun and streak—received at Aristotle's hands a unified theoretical treatment, incorporating the idea of reflection from water droplets in a cloud. At least once, the notion of ice crystals was floated for the mock sun.[37] Other ancient researchers discussed refraction, but, judging from Alexander of Aphrodisias' comments on the

[34] [Thphr.] *Sign*. 22 and Arat. 882 explicitly describe ordinary mock suns as located to the "north" and "south" of the real sun. Illogically, the modern authors E.W. Webster in Ross (1931) 372a10 and Tricot (1941) 187 have described the relative positions as "east" and "west."

[35] The *Historia Augusta* wrongly associates this prodigy with the death of Pertinax earlier the same year.

[36] 223 BC: Plu. *Marc*. 4.1; Oros. 4.13; Zonaras 8.20. 217 BC: Liv. 22.1.10; Oros. 4.15; and n. 32. 122 BC: Plin. *Nat*. 2.99; Obseq. 32; Apuleius in Lyd. *Ost*. 4. Böker (1962) 1675 has treated the "night suns" (*sol noctu*) of the Roman prodigy lists as mock moons, but these are almost certainly auroral displays, which Pliny's (*Nat*. 2.100) description and an apparent adherence to an approximately 11-year periodicity both indicate.

[37] Ideler (1836) 321 was the first to pick up on this prescient speculation.

halo, the theory probably involved refraction at the smooth surface of a cloud rather than refraction at the surface of individual water droplets.[38] Thus, some progress was made toward a modern scientific picture, but the ancients' reliance on analogy and the unquestioned paradigm of a mediating cloud remained stumbling blocks for centuries.

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[38] Refraction in antiquity has been discussed for atmospheric phenomena by Ideler (1832) 180–6; Boyer (1956) 383–6 and (1959) 61; Kidd (1988) 498; Ross (2000) 863–71; Lehn and van der Werf (2006) 5624–9; Sider and Brunschön (2007) 166. Although little is known about the ancients' application of refraction to rainbows, haloes and mock suns, a number of less prominent phenomena were interpreted after Aristotle's time in terms of refraction, namely, aerial perspective enlargement of objects, mirage, sun and moon size illusion and below-horizon visibility of the sun, moon and stars. But no equivalent of Snell's law connecting the sines of the angles of incidence and refraction seems to have been discovered during antiquity.

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Table 1. *Solar Haloes and Light Crosses*

| *Date* | *Place* | *Description* | *References* |
|---|---|---|---|
| 203 BC | Frusino | Two haloes | Liv. 30.2.12 |
| 147 | Lanuvium | Two haloes, red and white | Obseq. 20 |
| 121 | Italy | Rainbow-like halo | Plin. *Nat.* 2.98 |
| 114 | Italy | Halo | Plin. *Nat.* 2.98 |
| 90 | Italy | Red halo | Plin. *Nat.* 2.98 |
| 44 | Rome | Rainbow-colored halo | Vell. 2.59.6; Sen. *Nat.* 1.2.1; Plin. *Nat.* 2.98; Suet. *Aug.* 95; D.C. 45.4.4; Obseq. 68; Oros. 6.20; Lyd. *Ost.* 10b; Zonaras 10.13 |
| AD 94 | Greece | Rainbow-like halo | Philostr. *VA* 8.23–5 |
| 208 | Syria | Halo | Lampr. *Alex. Sev.* 13.5 |
| 270 | Alexandria? | Halo | Michael the Syrian 6.9; Bar-Hebraeus 8.57 |
| 312 | Italy | Cross | Eus. *Constantine* 1.28 |
| 351 | Jerusalem | Cross within rainbow-like halo | Cyril of Jerusalem, *Letter to Constantius* 4.17–23; Philostorgius 3.26; *Chronicon Paschale* Olymp. 282 |

Table 2. *Mock Suns*

| *Date* | *Place* | *Description* | *References* |
|---|---|---|---|
| 525 BC | Egypt? | Two suns | Lyd. *Ost.* 4 |
| 206 | Alba | Two suns | Liv. 28.11.3; 29.14.3; Claud. *In Eutropium* 1.7 |
| 174 | Rome | Three suns | Liv. 41.21.13; Plin. *Nat.* 2.99 |
| 166 | Rome? | Two suns | Cic. *Rep.* 1.20–1 |
| 163 | Formiae | Two suns | Obseq. 14; Claud. *In Eutropium* 1.7 |
| 129 | Rome | Two suns | Cic. *Rep.* 1.15–32; *N.D.* 2.14 |
| 122 | Gaul | Three suns | Obseq. 32 |
| 118 | Rome | Three suns | Plin. *Nat.* 2.99 |
| 104 | Picenum | Three suns | Obseq. 43 |
| 44 | Rome | Three suns, one within a spiky halo | Plin. *Nat.* 2.99; D.C. 45.17.5; Obseq. 68 |
| 42 | Rome | Three suns | Plin. *Nat.* 2.99; D.C. 47.40.2; Eus.-Jerome *Chronicle* Olymp. 184; Obseq. 70 |
| AD 51 | Rome | Three suns | Plin. *Nat.* 2.99; Apuleius in Lyd. *Ost.* 4 |
| 69 | Rome | Two suns, east and west | D.C. 65.8.1; Lyd. *Ost.* 4; Zonaras 11.16 |
| 193 | Rome | Three stars surrounding the sun | D.C. 74.14.4–5; Capitol. *Pertinax* 14.3 |